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ELEMENTS OF DESIGN REVIEW FOR SPACE SYSTEMS

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Foreword

The term "design review" has found a rather wide use in recent years both in aerospace industry and in Government. However, depending on the user or context of use, the term is applied to a fairly wide range of scopes and kinds of activity. NASA Reliability Publication NPC 250-1, entitled "Reliability Program Provisions for Space System Contractors," prescribes design review as one of the activities necessary to the development of NASA hardware. Although the language in NPC 250-1 is explicit in describing the basic purpose of the design review task and a number of specific contractor and Government actions in support of the requirement, the scope and purpose of NPC 250-1 do not permit a full illustration of the range of functions by which design review should serve a hardware development program (a) at various levels of assembly, (b) at various milestones in the development process, and (c) in projects of differing size and significance.

The present publication has been structured to describe the design review activity, not only in its overall aspect but also in its operation at each of the various hardware levels, program milestones, and project types. The approach is to provide a generic and functional description without expressing any procedural preferences except on grounds of effectiveness in accomplishing the purpose of the review activity.

It is the objective of this publication to serve as an information tool to assist NASA personnel and installations in communicating with their contractors on design review. The procedures and elements of reviews covered here are intended to be descriptive and not mandatory.

The principal author of this document is R. E. Boss, who was assisted by C. H. McGaffin, both of the Martin Company, and the effort has been guided and edited by D. S. Liberman of this office. However, significant assistance has been provided by all NASA field installations and Headquarters program offices in constructively reviewing and commenting on the drafts, and this is gratefully acknowledged.

Although developed under contract (NASw-1128), this publication incorporates many comments reflecting NASA experience beyond that of the contractor. The result, therefore, reflects a considerable breadth of engineering management experience by NASA and its contractors.

John E. Condon, Director
Reliability and Quality Assurance Office

Contents

chapter		page
	SUMMARY	1
1	DEFINITION AND PURPOSE	3
2	ELEMENTS OF DESIGN REVIEW	5
	Review Team	5
	Responsibility and Authority of Chairman and Team	6
	Customer Participation	7
	Review Frequency	8
	Data Inputs	10
	Data Outputs	12
	Continuity and Followup	13
3	REVIEW CATEGORIES	15
	Preliminary Design Review	15
	Prepackaging and Prerelease Design Reviews	21
	Acceptance Review	25
	Special Purpose Reviews	27
4	APPLICATION	32
5	COSTS	35
	Examples of Programs	35
	Comparison with Industry Practices	36
	APPENDIX A–DEFINITIONS	51
	REFERENCES	55
	BIBLIOGRAPHY	57

Summary

This present publication is intended to serve as an aid for instructing technically trained personnel in the implementation and evaluation of a design review program. It describes in detail those reviews performed by the contractor with customer participation and touches lightly on the various reviews and buy-offs conducted by the customer.

A design review program is a systematized and disciplined application of the broad technical competence of the contractor and the customer to a product. It is the only technique for independent evaluation of a product prior to the testing phase and is a necessary technique for the achievement of reliability. The basic objective of a review program is to provide assurance to customer and contractor management, by formalized documentation of the decision logic, that the design satisfies the program requirements. Detailed objectives of the design review (from ref. 1) are:

(1) To evaluate the capability of the design to meet the total system requirements
(2) To determine the effects of procurement, assembly test, shipping, storage, human factors, and maintenance on the achievement of the design goals
(3) To identify problems of process control, production, and parts and material procurement
(4) To consider the effects on performance of proposed configuration changes
(5) To evaluate the operational functions of the design with respect to the current known state-of-the-art
(6) To evaluate the adequacy of the specification to meet the intended operational use
(7) To determine whether the design conforms with the specification requirements
(8) To provide for optimization of design within the functional performance requirements

The elements of a design review program are:

(1) Review-team makeup
(2) Responsibility and authority of chairman and team
(3) Customer participation
(4) Review frequency
(5) Data inputs
(6) Data outputs
(7) Continuity and followup

To satisfy the objectives of the design review, the review team must have a collective technical competency greater than that of the designer(s) of the design being reviewed. There are several resources for achieving this competency:

(1) Permanent reviewers
(2) Recruited specialists
(3) Staff or consultant authorities
(4) Various combinations of the above

Selection of the team makeup for the various levels of review should be based on the advantages of each approach discussed in this publication.

It is the responsibility of the design review activity to direct program management attention to design deficiencies while correction is still chronologically and economically feasible. The review team may, or may not, have directive authority; however, in any case the review documentation must not be censored, whether the recommendations are accepted or not.

The participation of Government representatives in design reviews is both necessary and desirable; it is necessary since one objective of the review is to assure the customer that the design will satisfy the system requirements, and desirable since the customer will have inputs not otherwise available to the contractor. Contractual implications of directions by the Government representative usually require separate discussion, since the design review team will not include specialists in that field.

The scheduling of a design review program properly related to program significance, system complexity, and design milestones is probably the most difficult of the program elements. Factors to be considered are:

(1) Program significance
(2) Complexity
(3) Technical background
(4) Cost

Reviews may be grouped into milestone categories generally applicable to any design and development effort. These are:

(1) Preliminary design review at system, subsystem, and component level
(2) Prepackaging review, for electrical and electromechanical components
(3) Prerelease review, for all components prior to manufacture, also at subsystem level by concurrent reviews at component level
(4) Acceptance reviews, for all levels
(5) Special purpose reviews and buy-offs

Data provided to the review team prior to the review will vary in specifics with the particular milestones but in general must define the item being reviewed, give the requirements of the item, and describe its interfaces with other items.

Documentation of the design review must record the team makeup, the review level, the input material, the decision items (not just action items), and the decision logic that established the validity of subsequent corrective action as well as the confidence that management (contractor and customer) assigns to the product.

Continuity in a design review program is particularly difficult to achieve and depends to a large extent on the documentation of previous reviews. Current reviews must avoid rehashing the old problems. Followup is necessary to make certain that appropriate design change action has been taken or that additional study has validated the original design.

Application of the precepts of this publication will result in a reduction of end costs of any program through prudent and timely investment of manpower to reduce the larger cost risks of subsequent failure. However, for planning purposes the apparent cost of a design review program properly related to program significance and complexity will be between 1 and 2 percent of the total engineering effort.

CHAPTER 1

Definition and Purpose

NASA Reliability Publication NPC 250-1, entitled "Reliability Program Provisions for Space System Contractors" (ref. 2), states that the contractor should establish and conduct a formal program of planned, scheduled, and documented design reviews at the system, subsystem, and major component level.

A design review program is a systematized and disciplined application of the broad technical competence of the contractor and the customer to a product. Its purpose is to improve the product where necessary and to provide assurance to contractor and customer management, by formalized documentation of the decision logic, that the most satisfactory design has been selected to meet the program requirements. In creating this program requirement, NASA has expressed the need for additional control and visibility in the development process.

The primary purpose of the present publication is to describe in further detail for technically trained personnel the various functional elements of a design review program as called for in NPC 250-1 (ref. 2). This present publication also describes generically several of the various types of customer reviews and buy-offs which are used to verify the adequacy of the design and the hardware in program phases subsequent to design (and sometimes even during the design phases).

Because of the wide diversity of NASA programs, which range from unmanned probes evaluating single facets of the space environment to the bulk transportation problem associated with manned interplanetary travel, there is room for many interpretations of the design review process. However, the design review function, no matter how applied, should have certain attributes in order to be effective:

(1) It must provide an objective examination of the design by persons other than the designer.
(2) It must be conducted by a limited number of competent engineers, each with a competency at least equal to that of the designer in his own technical specialty but still sufficiently practical to maintain communication with other participants.
(3) It must serve to discipline the process of documenting the design decision logic.
(4) It must foster an atmosphere of free discussion of the designer's conclusions and the process by which he reached them. It must never take on the atmosphere of a board of inquiry whose object is to put the designer on the defensive.
(5) It must include provisions for effective review of subcontractor designed items.

The scope of the design review program will normally be defined contractually in the reliability program plan; however, this does not imply that the conduct of the design review program is a reliability function.

This publication describes a design review program conducted by the contractor with customer participation. In this type of program there are no customer conducted reviews prior to the buy-off activities of acceptance review, special readiness reviews, and flight readiness review. However, it should be noted that there are also programs, particularly in the manned space area, where the customer conducts most of the major reviews even during the design phase, although the contractor makes the review presentations. Reviews of this type, while generally analogous to the preliminary, prepackaging, and prerelease reviews described here, will differ in that the review team usually has directive authority (via appropriate contractual arrangements) and the reviews have some characteristics of an intermediate customer buy-off.

The following chapters discuss the design review process from several aspects. Chapter 2 covers the basic elements of the review process including the reviewers and their responsibility, the scheduling of a review program, data inputs and outputs, and followup on recommendations. Chapter 3 discusses the technique of review as applied to successive program milestones and levels of hardware; it covers not only true design reviews but also some buy-off activities. Finally, Chapter 4 briefly treats the proper scope of review programs for different projects, and Chapter 5 shows the costs of a design review program as applied to three typical programs of differing magnitudes.

For the reader's aid, a list of definitions of terms and abbreviations used in this publication is given in Appendix A. Also, a list of publications of further interest is given in the Bibliography.

CHAPTER 2

Elements of Design Review

A design review program consists of a series of reviews at various hardware levels at successive milestones in the life of the project. However, the approach to the program in terms of seven basic elements can have a considerable influence on the overall effectiveness. These elements are:

(1) Review-team makeup
(2) Responsibility and authority of chairman and team
(3) Customer participation
(4) Review frequency
(5) Data inputs
(6) Data outputs
(7) Continuity and followup

Each of these elements and its importance to the program are discussed in the present chapter.

REVIEW TEAM

General

In order to satisfy the objective of the design review, the review team must have a collective technical competency greater than that of the designer(s) of the design being reviewed. If this collective advantage does not exist, the program will not satisfy the objectives. (The designer will be placed in a position of having to lead the review, and, in a sense, interrogate himself.)

Team Compositions

There are various resources for achieving this technical competency. The principal ones are:

(1) Permanent reviewers
(2) Recruited specialists
(3) Staff or consultant authorities
(4) Combinations of above team compositions

Permanent Reviewers

A permanent review-team nucleus can be established with manning broad enough to handle all levels of review. The basic composition can be senior staff-level engineers of the contractor organization. The individuals need not necessarily be the "number one" men in their respective specialties, since use of their collective capabilities and disciplines will satisfy the review program objectives. Of course, they must have recognized capabilities in the specialties. This nucleus will contribute a cohesion and directional force not available with other techniques.

Recruited Specialists

Specialists can be gathered from other programs and staffs on demand. These persons, by virtue of the variety of their specialized viewpoints and isolation from the pressures of schedule and prior commitments, can supply knowledgeable unbiased criticism of the design. These teams will be high in individual competency but weak in preparation and motivational force. Utilization of these specialists subjects the design to perceptive scrutiny which may well bring to light areas for improvement in performance or reliability. However, it is difficult for personnel with no previous contact with a program to evaluate properly the equally important trade-offs of cost, schedule, customer desires, etc.

Staff or Consultant Authorities

Technical authorities, either staff or consultant, can be utilized to achieve the required collective competency. Here again the design benefits from a knowledgeable examination with application of state-of-the-art principles. However, the inputs of the authority must be limited to his area of specialty in order to avoid suggestions for changes which are too extravagant or subjective to be accepted by management (whereas limited objective changes might be accepted). The review effort should not result in design improvement without sufficient cause.

Combinations of Above Review-Team Compositions

Combinations of the above personnel depend on the circumstances of the contractor and the item under review. Where circumstances dictate the combination approach, the selection of teams for various levels of review should be based on the relative advantages discussed below.

Summary

The team compositions discussed above have their strengths and weaknesses when applied to various levels of review. In general, the inputs of technical authorities are more useful in the conceptual stages, where freedom of thought is not restricted by cost of implementation (hardware, test, and paperwork revisions). However, corrective measures take on a more practical aspect as the design progresses into the detailed phases. Here the authority might be consulted in the face of apparently insurmountable problems, but for the most part detail problems can be resolved and the design crystallized by application of basic design principles by a broadbased, hardware-oriented review team.

Regardless of the technique used, the review team must have sufficient breadth to handle the several aspects of the review item (performance, reliability, cost maintainability, etc.) and the interfaces and interactions with adjacent items.

RESPONSIBILITY AND AUTHORITY OF CHAIRMAN AND TEAM

It is the responsibility of the design review activity to direct program management attention to design deficiencies while correction is still chronologically and economically feasible. The following discussion treats specific obligations of the design review participants.

Management has the responsibility for providing a favorable climate for the design review program including assignment of personnel, time for preparation, and so forth. This can best be accomplished by including a specific item in project cost negotiations for design review at the outset of the program. The reliability program plan should include a comprehensive schedule of the needed reviews relative to design milestones. The reliability organization has the responsibility for including the coverage in the plan.

The review-team chairman must define the input data package, set the agenda, and document the meeting; the coordinator must bring about the preparatory activities, secure the services of required outside personnel, and inform the customer of review-team activities.

The review team has a responsibility to prepare for the review by utilizing fully the data given them. A review that degenerates into a low-level education program will be wasted.

Although the members of the review team must have authority to call for additional technical competency (specialists, consultants, etc.) or additional data, they must not transfer their responsibility to the technical "expert." His testimony must be considered as only one input to be balanced against other significant factors (program impact, necessity, alternate designs, etc.).

Review-team personnel must accept responsibility for the pertinency and adequacy of the team output, and project management must assume that the output is a responsible attempt to fulfill the review objectives. This is necessary in order to create the proper atmosphere for conscientious design evaluation even though the responsibilities of the review team stop short of accomplishment of the recommended improvements. The review team may or may not have directive authority for initiation of corrective action. Where it does not, its function is advisory to the contractor program manager rather than directive; his office, in turn, triggers the corrective action process if the recommended action is approved. If the recommendations are not accepted the review documentation must not be censored; the logic of rejection itself must be documented. It is the responsibility of the review-team chairman to ensure that this has been done by management.

In some cases the review team does in effect have directive authority (such as where the project manager or his immediate deputies act as chairman). Here, trade-off decisions may be made in the review itself, wherein prime candidate solutions to design problems may be rejected because of program constraints other than technical ones. In such situations, the review report must document both the proposed solution and the logic of rejection.

The selection of the review chairman and assignment of his duties are management prerogatives dependent on many variables, such as availability of personnel, review level, and program significance. Some organizations use permanent chairmen while others may use technical department heads or staff engineers. Duties of the chairman as they relate to specific reviews will be discussed more fully in subsequent chapters. The value of a specific review will depend greatly on the manner in which the chairman carries out these duties.

The necessity for complete objectivity (i.e., the ability to criticize the design without injection of personal or technical prejudice) on the part of the design review team is frequently mentioned; however, the design review effectiveness can be as severely restricted by unconstrained objectivity as by lack of objectivity. On the one hand, lack of any degree of objectivity, that is, a tendency to perform design review completely within the confines of program constraints (including schedules, costs, etc.), subjects the mental processes of the review team to the same restrictions as those under which the designer(s) has been functioning. A good technical solution to a design weakness may be ignored in consideration of an unduly restrictive concept of program constraints. On the other hand, the reviewer must have some realistic concept of program constraints; and unless he attempts to remain within this concept, he is apt to propose extravagant or unnecessary revisions. The management rejection prerogative may prevent serious damage to the program effort; however, the review functions of design improvement and assurance are sidetracked in the process. A marginal design is not improved when an extravagant revision is rejected, and the assurance of adequacy of the existing design is lessened when an unnecessary change is proposed. Furthermore, management's confidence in the review effort decreases with increase in impracticality of the outputs.

It is the responsibility of the review team to initiate inquiries into areas that appear technically weak and to introduce design alternatives for discussion. Objectivity tempered with the reviewer's concept of practical restraints is the key to a successful design review.

CUSTOMER PARTICIPATION

The participation of the customer (i.e., Government representatives) in design reviews is both necessary and desirable: necessary because one reason for design reviews is to assure the customer that the design will satisfy system objectives, and desirable because the customer will frequently have input information not otherwise available to the contractor which can significantly improve design and reliability or reduce the program cost. Their participation is particularly fruitful during the conceptual period, when associated customer experience and detailed knowledge of related projects can contribute to the establishment of sound basic premises. The Government representative should make known the necessity of any predetermined course which is based on constraints that may not have been available to the contractor.

The basic philosophy of design review is conveyed to the contractor by NPC 250-1 (ref. 2). It is incorporated into the reliability program plan and agreed upon at the start of the program. However, no matter how specific they may be, these requirements are still subject to interpretation in application. Coordination between customer and contractor during the initial working meetings affords an opportunity to clarify most differences of interpretation.

The attending Government representative must be subject to the same disciplines of preparation as those of the contractor personnel. Fifteen days prior to review (NPC 250-1, par. 3.6.1,b) the contractor will identify the review element, confirm the date and location, and present a data package. Like all attendees, the Government representatives must thoroughly familiarize themselves with the data package and be prepared to substantiate their views prior to the meeting. The 15-day notification may prove difficult in highly complex systems, but such systems will normally have an office for a resident Government representative at the contractor's facility, and this should facilitate communication and transmittal of information. A mutually agreeable reduction in notification time may be feasible in view of the complexity of the system and the extent to which the customer has been involved in the day-to-day design.

The contractual implications of directions from the Government representative will usually be determined by contracting and legal personnel, neither of whom is present at the review. Therefore, the in-scope/out-of-scope argument should not be injected into the review meeting. Normally, "scope" agreements generated at the design review are not binding, and the contractor has some specified time (as little as 5 days on some programs) to request contractual coverage.

Because the design review necessarily involves a critical evaluation of all aspects of the design, the conscientious contractor will frequently expose internal shortcomings to the collective criticism of the group. All members of the group should be most careful to use such information properly and objectively so as to prevent any reduction in its flow which would reduce the effectiveness of subsequent reviews. The ability of the participating Government representative to convince the contractor's personnel of his objectivity and discretion, particularly in this regard, can have a considerable influence on the effectiveness of the design review program.

REVIEW FREQUENCY

The scheduling of a design review program properly related to program significance, system complexity, and design milestones is probably the most difficult of the review program elements. The schedule provides the basis for both planning and estimation of manpower and costs and for evaluation of adequacy of the program. In this section, we will discuss the effect of several variables on the scheduling of reviews and the relation between the review program and the milestones of the design and development program. Subsequent chapters will demonstrate the applicability to representative design activities.

Influence of Project Characteristics

Program Significance

Any space-system program should be designed and developed to have a high probability of success, but we are willing to take more risk in some cases than in others depending on the program significance. The success of a program ranking high in the list of national objectives, such as a manned space program, is extremely significant, and the design and development phase will be scrutinized very closely.

Complexity

The complexity of the system also will determine the frequency of reviews. A complex system will require more reviews than a simple system, not only because of the larger number of system elements, but also because the interfaces become more numerous and more subtle.

Previously Proven Components

Use of previously proven designs in a new system can significantly affect the number of reviews required. In this case it is necessary to assure that the new usage is no more demanding in either performance or environment than the old and that the new interfaces are compatible with the equipment. The schedules associated with integration of those units into the new design are somewhat flexible. The advanced status of the development of those units permits some smoothing of the design and review workload with respect to time. However, prolonged delays should be avoided, since there is always the possibility that an unforeseen application problem might require a major redesign, and what was at first a flexible schedule might suddenly become a PERT critical path. Similarly, prior use does not assure availability of complete documentation of that usage, particularly when that data must cross company lines. A good initial step is to obtain and evaluate the supporting qualification test data for conformance to the standards and environmental levels of the new program.

Cost of Review Program

Cost or, more precisely, lack of money is seldom a valid reason (although frequently used) for decrease in the review frequency. Design review is a necessary technique for the achievement of a reliable design. Frequency of review will be dictated by the factors of significance and complexity.

Influence of Hardware Levels and Development Milestones

Once the frequency of the design reviews has been established on the basis of the above factors, the specific reviews relative to the system subdivisions and the design and development milestones can be defined. This definition is generally bound by standardized engineering practices; selection of hardware subdivisions for review is guided by the tecnhologies involved, and selection of the project milestones for reviews is governed by the sequence of steps in design normal for each of the various hardware subdivision levels and types.

Selection of system subdivisions usually follows the established levels of systems, subsystems, components, and parts. A system, as defined by Appendix A of NASA NPC 250-1 (ref. 2), is "one of the principal functioning entities comprising the project hardware and related operational services within a project or flight mission. Ordinarily, a system is the first major subdivision of project work. Similarly, a subsystem is a major functioning entity within a system." Thus, for NASA purposes, the system level is associated with the operational function, or mission, of a space activity. The subsystem level divides the overall activity into those technologies required to perform or support the mission. Representative examples include power and distribution (electrical), flight controls and guidance (electromechanical), and propulsion (mechanical). The next level of subdivision is the component. NPC 250-1 defines a component as "A combination of parts, subassemblies or assemblies, usually self-contained, which performs a distinctive function in the operation of the overall equipment," i.e., a "black box." Design review, as considered here, is not carried below the level of component. However, consideration of the application of parts and materials in the components, although detailed and time-consuming, is basic to the review of the component design. NPC 250-1, paragraph 3.9.6, requires specific reviews covering the application of parts and materials; the outputs of these reviews are an essential input to component design review. Another as yet unpublished manual of this series discusses those reviews in detail.

Reviews may be grouped into milestone categories which are generally applicable to any design and development effort. These categories are:

(1) The preliminary design review, sometimes called conceptual review
(2) The prepackaging review—prior to preparation of detail drawings
(3) The prerelease review—prior to release for qualification test unit production
(4) The postqualification review—immediately following qualification and preferably, but not usually, before start of production

(5) Acceptance review—prior to delivery to the customer
(6) Flight readiness reviews—following completion of ground testing

It should be noted that reviews (1), (2), and (3) above are design reviews in the purest sense of the word; usually they are conducted by the contractor with customer participation. Review (4) is functionally a private readiness review by the contractor to assess the readiness of the system for presentation to the customer for acceptance. Finally, reviews (5) and (6) are essentially buy-offs conducted by the customer with contractor participation.

It should be noted that the review categories above are selected by technical milestones and not by technical specialties. Formal reviews by specialty (e.g., reliability review and value review) are not advisable, since the objective of the review is to consider the trade-offs, compromises, and controversies. A system, subsystem, or component can always be made either more reliable or cheaper, but not always both. The proper trade-off cannot be appraised objectively by the concerned specialty. The needed perspective can only be achieved through joint evaluation by all concerned specialties.

Figure 1 presents a generalized milestone chart of a design and development effort such as might be encountered by a space-system contractor. The chart shows the completion points (milestones) of significant portions of the effort. Each point in the conceptual and component design stages is accompanied by a letter designation corresponding to the above listing of review categories to indicate the type of review to be conducted at that point. Review frequency should decrease measurably as hardware production commences since the basic job of design verification and trade-off through review must be completed by this stage for maximum effectiveness. Subsequent reviews, conducted at the system level, emphasize the assurance aspect, as implied by their names—acceptance review and flight readiness review.

The chart shows only a single sample of each milestone, whereas an actual project may be composed of any number of related subsystems and these in turn may contain numerous components. The chart is therefore a composite of numerous overlaid milestones (except for the system-concept milestone at the left and the "first article" milestones at the upper right).

Aside from the knowledge flow indicated on the chart, chronological independence exists. Unless multiple paths of flow exist (i.e., several concurrent activities are required) from one milestone to another, the efforts to achieve one milestone are entirely independent of those to achieve another and may be conducted concurrently or months apart; program schedules will determine procedure. For instance, the generation of circuitry for an electrical component is independent of the detail design of the structural subassembly into which the component will be installed. Similarly, the detail development of one component is independent of a second, since the interface data have previously been established in the subsystem conceptual stage. The parallel but time-independent efforts are represented by overlaid "component detail" milestones.

Frequently, a decision is made to permit full production prior to completion of qualification testing, as indicated by the dotted line around the test. That decision assumes acceptance of a risk of subsequent changes in order to improve schedule or reduce setup costs.

DATA INPUTS

Data provided to the review team prior to the review will vary in specifics depending on the milestone at which the review is being conducted, but in general they must define the item being reviewed, give its requirements, and describe its interfaces with other items. These data might normally be thought of as drawing(s), specification(s), and interface specification(s). For example, a component review of an in-house built item might require:

(1) Detail drawing (pictorial representation, descriptions of required materials, finish, dimensions, tolerances, fabrication, and assembly instructions, etc.)

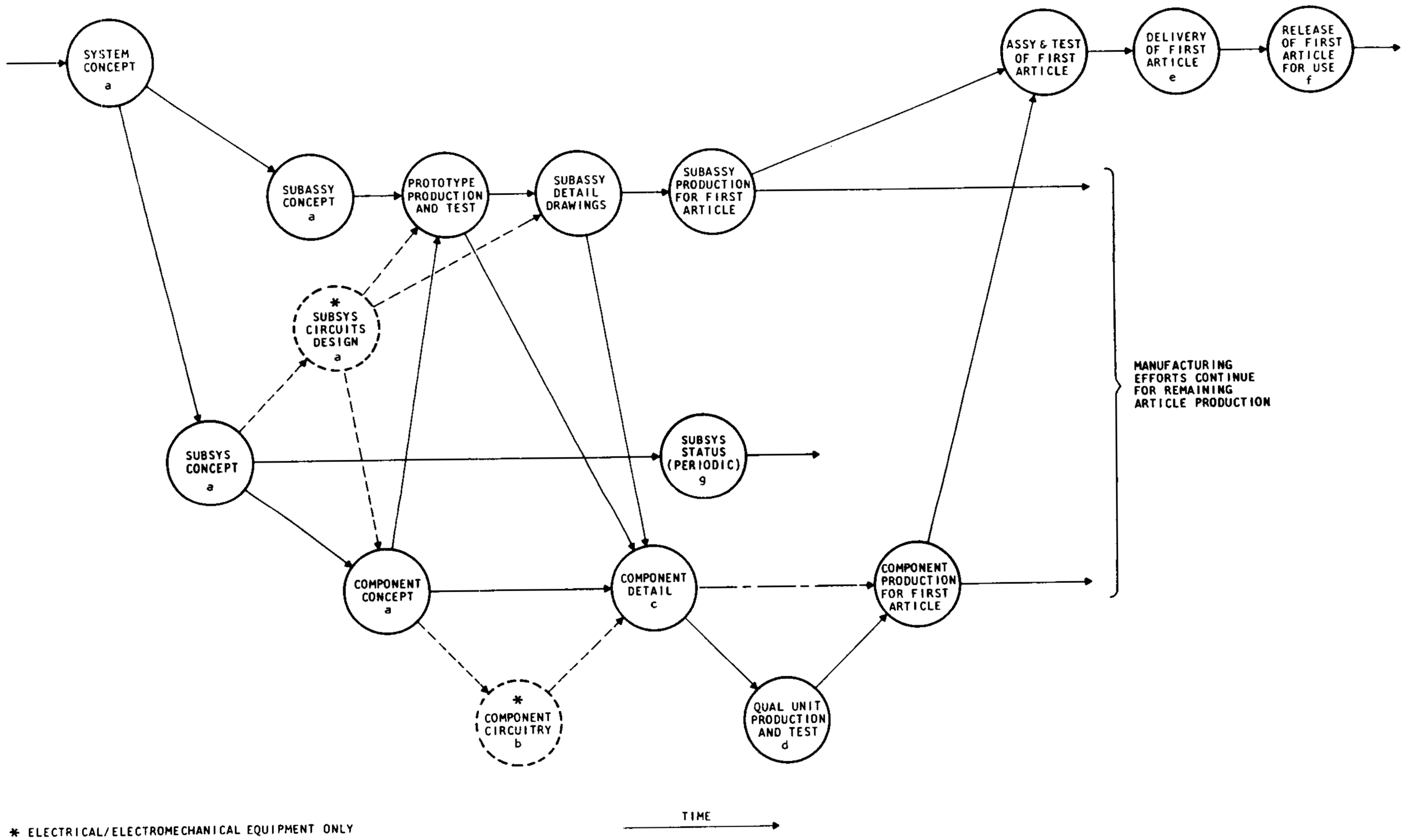

Figure 1.—Milestone chart of a system design and development effort. a, Preliminary design review; b, prepackaging design review; c, prerelease design review; d, postqualification design review; e, acceptance review; f, flight readiness review; g, subsystem status review.

(2) Installation drawing (general configuration, attaching hardware, and information to locate, position, and mount the item relative to a fixed reference)
(3) Circuit schematic diagram (function symbols with interconnections to illustrate circuit operation)
(4) Component specification (functional characteristics and test requirements to verify these parameters)
(5) Parts and materials application review data (detail reviews)
(6) Subsystem (or system) specification (for interface functional characteristics and test requirements)
(7) System design data report (system description and specific design requirements such as space and weight considerations, mounting requirements, special environments, design and checkout requirements, and maintenance provisions)
(8) System design criteria report (general design philosophy and ground rules)
(9) Reliability analyses and failure modes/effects analyses

The last four documents provide interface information and should reflect the latest mission requirements. A task in the review effort will be to verify that all mission changes have been implemented and that the component requirements have been reevaluated in terms of the changes. The important result of such a reevaluation of component requirements is that of assurance—the assurance that the design is capable of performing any of these new tasks under possibly increased environmental stresses. Assurance is also obtained that major design simplifications have been accomplished where possible to take advantage of associated reliability and cost benefits. This discussion is included in this section on data inputs (rather than that on data outputs) since the proposed evaluation of mission changes should be done in the preparatory phase rather than during the meeting. Applying any portion of meeting effort to obsolete design criteria is then avoided.

Subcontractor items should receive similar consideration except that the effort is usually divided into two phases, one at the contractor facility and a followup at the vendor facility. The initial phase includes review of interface and installation documents as described above to confirm the accuracy of the requirements in the component (or procurement) specification. The procurement specification is usually expanded to include not only performance requirements but some component details such as external dimensions, finish, mounting surfaces, and simplified schematics with the specific detail being left to internal vendor drawings. The second phase compares internal vendor documentation with the procurement specification.

In addition to the specific documents mentioned above, any review requires other more general types of information for design review data inputs. Documented results of prior reviews with management approval or disapproval and followup action summaries provide a basis for current discussions. Also, the cognizant designer(s) must bring to the review all pertinent backup data, for example, design and laboratory notebooks, test reports, analyses, and results of parts and materials application reviews. Similarly, the reviewer should be prepared to support with data his initial positions (i.e., questions on adequacy of the design).

DATA OUTPUTS

Basically, the data outputs of the design review activity must document: (1) the basis on which management (customer and contractor) has placed confidence in the product and (2) the logic that established need (or lack of need) for subsequent corrective action.

The usual listing of action items is inadequate by itself since the logic of rejection of other input recommendations may be more significant. Design review is basically a management decision-making tool, and management interest at a later date may center on one of the "no-action" items. The recorded logic of rejection of that item by the review team will assist in evaluating the new information. The same reasoning applies to later review efforts.

Similarly, a check list is of relatively little value unless it is used almost solely as a reminder device. A checked-off list contains none of the comments and considerations which lead to meeting conclusions and should certainly not be the sole output of the review.

The output documentation must record the team makeup, the review level, the input material, the decision items (not just action items), and the decision logic where it is not evident. It must be of sufficient depth to serve as a meaningful input to subsequent reviews and to management for approval of recommended action.

The report should have the concurrence of all meeting attendees. It is advisable that the report be generated as the meeting progresses with resolution of each item being secured prior to proceeding. Although this may appear at first glance to be prohibitively time-consuming, the advantages usually outweigh the inconvenience. Advantages include:

(1) Added incentive for preparatory phase. Prior research and written conclusions are more apt to receive recognition than an educated guess.

(2) Added directional control of meeting. Many hours can be consumed in a design review program by circuitous rambling. The chairman has a valuable tool in immediate documentation because it tends to keep the meeting objectives in focus. By rephrasing discussion thoughts into wording suitable for the report, he continually directs attention to the need for applicable, not extraneous, data.

(3) More accurate recording of consensus. Postmeeting documentation is dependent on one person's interpretation of meeting conclusions and usually involves some delay in being generated. Both conditions permit some distortion of the recorded logic. Conversely, on-the-spot composition secures concerted efforts at accuracy, particularly from the proponent of the particular idea under discussion; and the thought is captured while it is fresh in everyone's mind.

(4) Timely corrective action promoted. If concerted agreement is secured point-by-point on the spot, the major delays resulting from later disagreement with the accuracy of the recorded version of the meeting are minimized. Some variations of this technique may be employed to further accelerate publication of meeting results. Whatever the procedure, a timely and accurate report sets the pace for management and corrective action and clears the way for preparation for subsequent reviews.

If it is not considered feasible to prepare the report during the meeting, then, as a minimum, a summary upon which there is concurrence must be written prior to breakup of the meeting. This summary will serve as the basis for the subsequent report.

CONTINUITY AND FOLLOWUP

If we are to realize the potentials of the design review program, continuity must be maintained from meeting to meeting, and followup must be ensured until corrective action has been taken. Where valid design changes have been recommended and management has concurred in them, sufficient information must be carried over to successive reviews to avert repeated coverage of these same problems or to avert significant loss of insight. If continuity and followup are achieved, the next review effort can be immediately directed at new facets of the item.

Continuity is particularly difficult to achieve. Documentation provides a degree of continuity but is usually not complete enough in itself to stop subsequent discussions and misunderstandings. Complete personnel continuity is neither practical nor profitable. Practically, the same personnel are seldom available for repeated review-team assignments over a period of time, and, even if they were available, these people are seldom capable of handling all levels of review. Possibly a permanent chairman can lead all reviews on a given subsystem and its components. In any case, new reviews must avoid unnecessary discussion of the old problems.

Followup is necessary to assure that the benefits really accrue. A closed-loop system is required to make certain that appropriate design-change action has been taken or that additional study has validated the original design. One current system injects the action items directly into the hardware corrective action process and utilizes the existing followup mechanism to assure the same closed-loop management scrutiny of corrective action that hardware problems and fixes receive. In any case, whether the existing loop is used or a second directive system is generated, the followup that is prescribed by that procedure must become effective so that an exhaustively detailed followup by the design review team can be avoided.

CHAPTER 3

Review Categories

The present chapter covers the different categories of reviews identified with the program milestones at which they occur. These are:

Preliminary design reviews
Prepackaging (or breadboard) design reviews
Prerelease design reviews
Acceptance reviews
Special-purpose reviews
- Flight readiness
- System readiness
- Postqualification
- Subsystem status
- Functional
- Failure

The first three of these, which are truly design reviews, and the acceptance review are discussed in detail; also included are the hardware levels to which they apply and review elements. The six types of special-purpose reviews, which include both special reviews and buy-offs, are treated more briefly.

PRELIMINARY DESIGN REVIEW

The preliminary design reviews (PDR or conceptual reviews) are a series of reviews at system, subsystem, and component level which are intended to assure contractor management and the customer that the proposed solutions satisfy the mission requirements; that they are within existing technologies; that manufacturing and test facilities are available in timely fashion; and that contractor personnel are technically qualified, or, conversely, that subcontracts are required. On the basis of results of preliminary design reviews, design requirements (specifications) are established.

These reviews require the concentrated effort of a broad cross section of personnel and may well result in major redirection of program effort. The preparatory phase of the preliminary review normally requires evaluation of major trade-off studies, as, for example, mission support equipment interfaces. Review findings may indicate the need for parallel development programs to assure the availability of an adequate design. In any case, the preliminary reviews must be complete evaluations of existing concepts in order to satisfy the management (customer and contractor) assurance requirement.

System Level

Purpose and Scope

Preliminary review at the system level is intended to evaluate the basic engineering approach to solution of the mission problem before considerable effort has been expended in the subsystem definition phase. A system design review is frequently performed by the customer in his selection of contractor or in his evaluation of the study phase. However, the review referred to in this text is a contractor effort which is conducted after mission objectives have been broken down and translated into subsystem requirements. By this time, system criteria are defined in terms of specific mission tasks, functional requirements, and environments. Launch-vehicle or spacecraft structure is outlined in general terms of size, weight, modular breakdown, and design philosophy. Major analyses normally have been completed in these areas, and, as a result, preliminary contractual specifications and design criteria have been established. Initial component requirements have been outlined in sufficient detail to ascertain contractor development capability or to determine that subcontracts are necessary.

The initial system design approaches to fulfilling mission objectives must be reviewed against all criteria thus far established, with the basic emphasis on completeness of coverage. To satisfy mission objectives, there are functions to be performed; equipment to perform these functions; tasks to be handled by each equipment; support equipment to manufacture, assemble, test, transport, and launch the flight system; facilities and personnel for each phase of operation; and so forth. The system design approaches must include all facets of mission operations applicable to the contractor and must be outlined in sufficient detail to define subsystem requirements. Complete coverage of these equipment requirements, including compatibility with customer defined interfaces of other mission systems, must be assured.

Review Team

Preparation for a preliminary system-level review requires the participation of a large cross section of personnel, with practically every project member contributing to the data input package. However, the formal review is performed by key personnel of both contractor and customer.

The contractor's chief engineer (in a large organization, the chief engineer of that division responsible for the project) usually performs the function of chairman. The chief engineer is the person in charge of all technical activity in the organization, whether he is called director of engineering, vice-president of engineering (as in small companies), or some other title. He selects the basic review team from among staff engineers in his own organization in order to assemble as well-rounded and coordinated a team nucleus as he can muster. Note that the two required characteristics of this nucleus are breadth of experience and an ability to communicate ideas. The basic preliminary review team will seldom be self-sufficient and must have the breadth to recognize the need for additional specialist opinions.

Although a case could be made for inclusion of representatives of each of the engineering specialties contributing to the system development, the resulting review would be completely unwieldy. Normally the reliability and human factors engineers are expected to cover the assurance and user aspects, while requirements for other specialized aid must be recognized by the review team. (See tables 1, 2, and 3 for team makeups for preliminary system reviews of various types of projects.)

Customer representation is essential during this review, in view of the far-reaching implications of the decisions. Trade-off study recommendations, for example, might involve the design philosophy for an entire subsystem and a firm decision to act on the study recommendations requires customer concurrence. In extreme cases, information may prove inadequate for resolution, and additional study or parallel development using each technique will be needed. In addition to the need for his concurrence with decisions, customer participation is valuable from an information-input viewpoint, since the customer has access to advanced developments and state-of-the-art innovations throughout the aerospace industry.

Data Inputs

The preliminary system-level review requires, as data inputs, all existing documentation of system design limitations. This includes such specification items as:

(1) System performance
(2) Environmental criteria

(3) Interface definitions
(4) Acceptance criteria
(5) Vendor control definition
(6) Top drawings
(7) Test specifications
(8) Reliability predictions
(9) Failure mode and effects analyses
(10) AGE (aerospace ground equipment) and facilities requirements
(11) Design criteria reports

Reliability program plans (NPC 250-1, par. 2.2.1, ref. 2), quality assurance plans (NPC 200-2, par. 3.1.1, ref. 3), and similar items are other necessary inputs supplied by the applicable project management group. Since these documents will be in various states of completion and approval, the contractor proposal may be needed in some areas to supplement the information. Trade-off study reports from all design groups which illustrate design concepts discarded in favor of the present configuration (e.g., feasibility studies) are major data inputs.

In larger programs where significant components will be procured, it is usually necessary to have a "vendor control specification" to be contractually applied to subcontractors. In addition to the contractual basics, this document provides general technical information to enable compliance with reliability, quality, and documentation requirements. Provisions of this document should be reviewed for adequacy.

In the case of a second or subsequent item (spacecraft or launch vehicle) in a series, where there is significant design modification from item to item, the input documentation at the preliminary design review should include a summary of failure experience and correction in the late stages of testing and field use of the previous item.

Data Outputs

The output from a preliminary system-level design review is a comprehensive report documenting the conclusions reached during the review. Conclusions take the form of recommendations to the program management that specific portions of the system engineering effort be approved or that certain system concepts are unsubstantiated or are based on unsound analysis and need either substantiation or revision. As backup for the conclusions, the review report will:

(1) List all documents forming a portion of the system criteria by which specific subsystem requirements have been defined and from which subsystem design evolution will proceed (See preceding section on data inputs for specific documents)
(2) Assert that the boundaries defining system performance are completely and accurately established
(3) Document the logic by which other system concepts were analyzed and then discarded in favor of the selected approach and the trade-off considerations which enter into the selection of this approach
(4) Present alternatives to the recommended courses of action and their relative effectiveness (or ineffectiveness) in achieving mission objectives

When selection of the desired system is not fully substantiated, the recommendation may favor parallel development until the correct choice is clearly indicated. As a practical matter, the project manager may elect to make a selection among the alternate systems on the basis of some criteria other than technical. It is unlikely that this decision could be made without further thought, customer negotiation, or research, since the review team presumably had all current information available when the concurrent decision was reached.

Subsystem Level

Purpose and Scope

A preliminary design review is performed for each subsystem when its definition has progressed to the point that functional diagrams, schematics, block diagrams, and major component functional diagrams (or requirements sheets) are complete. The review assures that the proposed subsystem does satisfy the system requirements and objectives and that the schematics and proposed component requirements represent a technologically sound solution. The review may be a part of, or extension of, the system preliminary design review.

The subsystem preliminary review will prove most effective if it can be performed prior to initiation of negotiations for component subcontractors. (Basic system engineering precepts require complete definition of requirements independent of influences from existing hardware capabilities.) The exception to this rule occurs when a particular subcontractor has been included in the definition phase proposal. Where such a contract obligation exists, the characteristics of that component are a program constraint and can only be altered by customer direction. If review determines that basic program objectives are incompatible with continued use of the component, the recommendation to contractor management should request a formal detailed presentation to the customer for a contractual change.

It is recognized that subsystem development is an iterative process and that inputs from the component subcontractor must be fed back into the subsystem design; also, the desirability of use of an existing proven component may dictate changes to the subsystem concept. Occasionally, feasibility of a component must be established before a meaningful subsystem review can be held, and review schedules should be rearranged accordingly.

Preliminary design review at the subsystem level would not be complete in most cases without a review of the AGE subsystem. The major considerations of this review are the compatibility of the test and maintenance facilities with the flight hardware and their effect on operational readiness, safety, and performance.

This review should also include all significant test and maintenance facilities required to provide assurance data. These requirements become more and more complex as the gravity of the mission (i.e., the "program significance") increases. Although the evolution of support equipment lags behind that of the operational system (since the requirements for the former are determined from specific parameters of the latter), it is still necessary that the feasibility of the concept for such items as the checkout equipment be evaluated at least grossly at the same time the subsystem is evaluated. An important consideration of the review of test and maintenance facilities is the compatibility of interface parameters to avoid compromising operational system reliability. It will usually be the case that the checkout and maintenance equipment does not receive the design and management attention that the flight equipment does. However, it is essential that checkout equipment which must check the failure modes most probable in the flight equipment must not have, in itself, failure modes which have a high probability of accepting faulty flight equipment or of damaging good flight equipment.

Review Team

The subsystem preliminary design review requires much the same depth of personnel experience as does the system review; however, the aggregate knowledge centers on the technologies pertinent to the subsystem under review. In smaller companies the chief engineer will probably act as chairman; in larger companies the chairman will be selected from the ranking personnel in the particular technologies, such as heads of technical departments. Project personnel in a direct line of authority to the designer should not serve as chairmen, since they would be reviewing themselves. At this level, the basic contractor team may be self-sufficient but should not ignore the possibility of consultant inputs. Systems engineers who participated in the system review can contribute a degree of continuity to this review and thus reduce the necessary preparatory effort. The systems engineer will be alert to the possibility of omissions or incompatibilities in the subsystem definitions and constraints thus far established and to iterative requirements for modification of system definition.

Data Inputs

Data inputs include functional flow diagrams, task breakdowns, test specifications, design specifications, design criteria reports, schematics, and component requirement sheets for the subsystem in question:

(1) The functional flow diagrams will present subsystem definition in terms of those functions and their interfaces required to attain one or more mission objectives. Customer interface specifications should be integrated into the functional flow diagrams where another contractor's subsystem adjoins (physically or functionally) the subsystem under review.

(2) Task breakdowns of each function will be available from the initial design efforts. The breakdowns should show continuity and completeness of coverage through to the proposed subsystem solution as portrayed on schematics and component requirement sheets.

(3) Status summaries of parallel development efforts are required, along with customer documentation of any revisions to mission objectives.

(4) Updated contractual specifications should be available for reference to conditions applicable to the reviewed subsystem.

(5) The preliminary structures review requires inputs as to availability and adequacy of manufacturing facilities and plans for test of vehicle structural models.

(6) Reliability prediction, apportionment, and failure mode and effects analyses are important inputs.

(7) If there have been advance feasibility studies of a critical component, a report of those findings is necessary to reach any conclusions as to acceptability of the subsystem concepts which include that component.

(8) General reference documents include planning reports for reliability safety, logistic support, quality assurance, manufacturing, test, facilities, human engineering, etc. The policies in these plans were established as program measures to assure that mission objectives would be met and should carry over into the subsystem definition documents.

Data Outputs

The report of a preliminary subsystem review should furnish a level of confidence in the established functions and design criteria of the subsystem and its major components and in the schematic representing the proposed design solution.

Report recommendations should cover every phase of the review discussions and should culminate in suggested approval or disapproval of the specific documents comprising the subsystem design. Where individual specialties (reliability, maintainability, human engineering, safety, etc.) propose design revisions, a complete rundown of the advantages and disadvantages of alternate trade-off possibilities is advisable to facilitate the management decision.

Component Level

Purpose and Scope

All Components. The preliminary review at the component level consists of a review of requirements which will be expressed at this point with some formality as a preliminary component specification, i.e., a series of demonstrable criteria. The review is intended to assure that the criteria expressed in the component specification do satisfy the subsystem and system requirements.

In addition to the obvious physical and functional parameters of the specification, the review must cover the subtleties of performance, interface, testing, and handling which can grossly affect the reliability and cost if not adequately specified. These subtleties might include such items as duty cycles, susceptibility to or generation of electromagnetic interference, validity of qualification test environment and sample size, adequacy of test points and test equipments, validity of acceptance techniques, storage and shipping provisions, and life or cycle limits.

For the more complex components, the subtleties should also cover the determination of testing and data requirements necessary to verify the adequacy of part and material applications; however, because of its detailed nature, this determination can best be made in a separate preliminary parts and materials application review, the results of which are presented as an input to the component design review.

Qualitative criteria in a component specification should be avoided, and quantitative criteria should be demonstrable. When a reliability number is specified (i.e., required), means of demonstrating compliance must be included. This might be analysis, limited no-fail testing, or testing to prescribed confidence limits. Confidence should only be specified in connection with a specific demonstration. For components produced in-house, the result of the review should be a confirmation or refinement of the preliminary component specification.

Components To Be Subcontracted. When the component is to be subcontracted, preliminary component design review evaluates the initial specification for compliance with subsystem and system requirements, and formal vendor proposals, vendor selection, and subsystem contract negotiations develop the ultimately released component specification. For items in this category it is sometimes prudent to have the initial contacts with potential suppliers prior to the preliminary review, particularly if the contractor is not well versed in the particular technology. If the potential vendors uniformly indicate strenuous objections to a specific criterion, it is necessary to review the objectionable requirement at subsystem or system level for possible relaxation or system change. (In such a situation, an isolated vendor who will promise compliance should be regarded with considerable caution; one must be sure that his promise is soundly based and will not result in a problem later on.)

It is not intended that the preliminary design review replace, or even enter into, the normal selection process for component vendors. At review time, the component specification has not yet reached a negotiable form and is sometimes given a separate designation for procurement purposes.

Although vendor inputs and negotiations are useful in establishing realism in the component specification, they must not be made governing factors in relaxing component requirements essential for meeting important requirements of the subsystem or system.

The subcontract specification must clearly define all items necessary for compliance with the provisions of the system reliability, quality, and maintainability program plans. Specific reference (objectives and data requirements) to prepackaging, prerelease, postqualification, and acceptance reviews will ensure vendor awareness of this design tool during the negotiations. This will facilitate his program planning and understanding of contractor needs and also will permit early discussion and resolution of proprietary arguments.

Review Team

Makeup of the review team for a preliminary component review varies with the complexity and significance of the component to the subsystem design. A major component essential to safety and mission success warrants the attention of divisional staff specialists.

Customer attendance follows the same line of reasoning. Where complexity and program significance are great, the customer's industry-wide background in many fields can be utilized more fully. However, his presence in any preliminary review should be with adequate preparation and applicable experience. Availability of the right customer representative for a particular component review might pose a practical limitation on customer attendance.

Data Inputs

The primary inputs to the component preliminary review are:

(1) Component specification
(2) Subsystem design criteria report
(3) Preliminary vendor inputs
(4) Studies and analyses completed since subsystem review
(5) Parts and materials application review report (for complex components)

The subsystem preliminary review report, with disposition of decision items pertinent to this component, will provide a reference point for initiating the current review. Much modification and refinement of the component requirements through continued design efforts, subcontractor contacts, etc. have most likely occurred since the subsystem review, thereby dictating a re-evaluation of component concepts against updated mission objectives. Customer directives and documentation of contractor action should be evaluated during the review preparatory effort for effect on the component or its interfaces. Reference material that is sometimes required includes contractual specifications and plans for applying principles such as safety, maintainability, and reliability to system design.

Data Outputs

Satisfactory completion of a preliminary component review implies that the component definition as evolved is compatible with the system and subsystem requirements and with the physical limitations imposed by the design. The review report presents a critique of the component specification and an appraisal of it in relation to the requirements outlined in the foregoing section entitled "Purpose and Scope." Where alternate approaches to component design have been selected by the review team as being clearly superior to existing concepts, the report must provide program management with a description of the available alternatives, including trade-offs, design problems to be solved, program impact, and so forth. Finally, the report should document the exploration of questionable areas which did not result in change recommendations (since present design was found to be justified).

A management decision at this checkpoint is necessary only if review findings indicate a change is necessary. Upon concurrence with these findings, management will direct appropriate action by the pertinent design activity. In cases of nonconcurrence, a written explanation must be appended to the review report.

PREPACKAGING AND PRERELEASE DESIGN REVIEWS

Prepackaging and prerelease design reviews performed by the contractor will normally be limited to component levels. Although these reviews can be, and sometimes are, conducted at subsystem and system level, system reviews at this time in most programs tend to become unwieldy and do not provide the detailed look that is required. When it is performed at a higher level, it is usual to break the review into a number of smaller segments to be performed concurrently by the cognizant customer and contractor personnel.

Prepackaging Review

Purpose and Scope

A prepackaging review is held whenever a clearly defined design milestone exists between preliminary and prerelease reviews. The prepackaging review normally is limited to electronic or electromechanical components, where significant design decisions of circuit selection and analysis, part selection and application, and breadboard testing are clearly and necessarily separated from (and completed prior to) the packaging design effort. This review is also appropriate for science experiments on spacecraft programs. The review is intended to assure that the completed circuit will perform the required functions, will remain stable under all operating conditions, and has been balanced with respect to trade-offs of simplicity, standardization (circuit principles and parts), cost, reliability, power requirements, tolerances, and so forth. The review will assure that the application of parts and materials has been adequately reviewed. (See NPC 250-1, par. 3.9.6, ref. 2; this ancillary review is also described in an as yet unpublished document of this series.)

Packaging concepts should be analyzed as thoroughly as possible during the prepackaging review to insure consideration of such fundamentals as radio frequency interference control, heat dissipation, mounting requirements (shockmounts, alinement, etc.), weight, geometric space, pressurization, fuel compatibility, and so forth. It is apparent that the best parts, even though correctly applied from an electrical circuit analysis standpoint, still require proper packaging to operate under the environmental conditions on which the reliability predictions are based.

Review Team

The prepackaging review requires a small, highly specialized team, consisting of electrical or electromechanical design specialists (circuits and packaging) and a reliability engineer. The design specialist must specifically not be the designer of the component under review but an engineer experienced with circuits of that particular functional category. Hardware-oriented personnel are best suited to this effort. Across-the-board customer participation may be difficult to achieve. However, customer representative attendance should be stressed in specific reviews of high-complexity components.

Data Inputs

The major inputs to the prepackaging design review are:

(1) The electrical circuit schematic, component specification, and packaging concepts (from the design group)
(2) Parts and materials application review reports
(3) Reliability analysis and the applicable design criteria report (from systems engineering)
(4) Other supporting data furnished by the designer including circuit analyses, breadboard test results, and pertinent design notes

Data Outputs

The report of a prepackaging review will do one of the following:

(1) Recommend proceeding with the component packaging detail effort on the basis of acceptable circuit design
(2) Include the logic of rejection of the present approach and suggested alternatives

It will also include data substantiating the positions taken. Acceptability of the parts and materials application review is recorded along with conclusions regarding completeness and accuracy of analysis and test data. Rejection arguments should establish the impact of present design on subsystem operation, so that the potential problem may be defined. Precautions in packaging should be noted in order to provide inputs to both the packaging designers and subsequent design reviews.

The report is submitted to project management, specifically, the assistant technical director responsible for design drawing signoffs, for action as indicated above.

Prerelease Review

Purpose and Scope

Prerelease reviews are held just prior to the release of engineering drawings for manufacturing. They are applicable to all elements of the system including science experiments. They provide the greatest potential for discovery of detail problem areas. Here, as with prepackaging reviews, the activity usually is conducted at the component level. At this time the designers consider their design to be complete; all development and evaluation tests have been completed. The output data from the prior reviews, including action items, are available. Only qualification testing to demonstrate that the design has its specified capability remains. This prerelease review is the last chance to prevent premature submission of an immature design to qualification testing. (Historically, the designer's confidence is seldom justified and changes will be required as a result of qualification testing. During the Gemini Launch Vehicle qualification program, for instance, components experienced 176 failures in 962 tests, and the Mariner MM-64 experienced 58 failures in 805 tests (ref. 4).)

The prerelease review will be directed to the detail hardware and will cover the following points:

(1) Has the packaging altered the circuit characteristics (previously reviewed in the prepackaging review)?
(2) Has the designer considered the qualification test as a design requirement (and possibly the most severe requirement)?
(3) Have the parts and materials application data been updated to include latest configuration and part-use data?
(4) Did the evaluation testing really evaluate the hardware relative to its capability for passing qualification?
(5) Where qualification by similarity is claimed, are both the hardware <u>and</u> <u>the</u> <u>usage</u> really similar to the cited example? (An item may have been previously qualified but may now require additional testing because of changes in mission environments.)
(6) Can this design be manufactured, inspected, and readily tested?

Included are reviews of specifications for manufacturing checkpoints, acceptance test environment, quality controls, and qualification test stresses, as well as the storage, installation, transportation, ground test, and flight environments. Results of prototype manufacture and test are necessary inputs to this review in order to obtain a preview of the probability of success of the manufactured version. These questions are not, of course, intended as a check list but only to indicate the direction this particular review should take.

The similarity decision, touched on above, is important to many NASA programs. The arguments for use of off-the-shelf components are economically luring and often technically valid; however, we seldom get them truly off-the-shelf. Lapses in production, incorporation of seemingly innocuous changes, or differences of usage can adversely affect the performance history we <u>think</u> we are buying. Review must be carefully performed.

The limited production quantities frequently required by NASA contracts induce additional problems. The unique tasks frequently require nonstandard components. The development of these components never achieves full maturity, and it is not economically feasible to design for mass production. Random selection of the qualification units from the production lot is not feasible since reason demands that qualification be complete prior to the acceptance review. The first units off the line are usually allotted to qualification testing. Sometimes schedule and budget commitments dictate the use of a prototype unit for testing if it has been built by the manufacturing department rather than a model shop. A certain amount of hand grooming during manufacture is not necessarily bad, unless the qualification units begin to receive some extra touches not afforded the delivered hardware. Frequently, qualification is achieved but subsequent "builds" cannot pass acceptance testing.

These problems should be anticipated and the design reviewed from a producibility standpoint in the prerelease review. Every effort should be made to relax manufacturing tolerances and eliminate difficult process requirements if other trade-off considerations permit. The time for manufacturing inputs to the detail design is prior to drawing release, and design review should assure that this critical function is performed.

The prerelease review also exercises the tact and diplomacy of the review team to a maximum. The designer feels he has finished, and always has an imminent schedule release date. He is ready to go to the next job and does not wish to answer a lot of "unnecessary" questions about the one he just finished. However, as indicated above, this review is extremely important and must be carried to a conclusion.

The prerelease review is applicable to all major components of the flight operational system and any items of support equipment considered critical to launch safety or mission reliability. It is frequently not conducted at subsystem levels since release of the detail component drawings within the subsystem may occur at widely different times.

Review Team

A team of hardware-oriented personnel, including some members of the prepackaging review team, is needed to accomplish the prerelease review. In addition to the designer, a hardware design specialist, a manufacturing tool designer, a reliability engineer, and an environmental test engineer provide the necessary skills for most of the required evaluation. Additional contractor participation may be required and secured during preparatory activities for specific reviews; this may include written inputs or direct participation by maintainability, human factors, safety, materials, quality control, value, and logistics personnel. Here, as with prepackaging reviews, customer attendance across-the-board may be difficult to achieve because of the large number of components involved.

The treatment of a vendor-built item must be handled discretely. A subcontractor team will frequently visit the contractor plant to present the design. This team probably will include senior technical representatives (particularly from smaller vendor houses) and a sales representative to protect the vendor's proprietary data. (In some cases, this complication requires that the review be conducted at the vendor facility.) Access to vendor internal drawings for design review purposes should be negotiated and assured <u>at the time the work is contracted</u> to facilitate the scheduled reviews.

Data Inputs

The primary input to the prerelease review is the completed set of assembly drawings showing the planned package configuration of the production component. Review attention centers on this compilation of detail information to evaluate the completeness and effectiveness of the proposed design solution with respect to the component test specification and to system performance requirements. The remaining data inputs provide support information on which to base a decision to accept or modify the assembly (detail) drawings. Included in the data package will be:

(1) Component procurement specifications
(2) Prototype test results
(3) Documentation of previous reviews
(4) Parts and materials application review report
(5) Reliability predictions
(6) Failure mode and effects analyses
(7) Manufacturing processes and techniques

(8) Cost analyses
(9) Qualification schedules and procedures
(10) Alternate designs

It is suggested that actual models be made available to team members for visual evaluation, if at all possible. A prototype test unit, partially disassembled, will assist in focusing review team attention on specific design areas. Even if the model is only a preliminary version, it will provide a basis for visualizing the final drawing configuration. Prior use of similar components should not be overlooked as a possible source of representative hardware.

Data Outputs

The end product of the prerelease review is a recommendation to contractor management that the component detail drawings be released for qualification testing or that specific design revisions are needed prior to release. The recommendation is substantiated by a point-by-point evaluation of the effectiveness of the component. Affirmative answers to the general questions posed in "Purpose and Scope" at the beginning of this section are essential, so each detail decision must reflect the component capability of being produced, performing the required functions, and surviving qualification environments.

Although the usual function of the review output documentation is to provide advice to the project technical management and to assure retention of the review proceedings, the component reviews in particular can provide cogent inputs to the reviews of similar components. For example, one group engineer avoided a diode problem that plagued all the other groups designing similar equipment. His novel treatment was completely missed during the design phase and was not recognized until analysis of failures on the other components was initiated. Adequate design review output records could have informed those concerned much sooner.

ACCEPTANCE REVIEW

Purpose and Scope

The acceptance review is the primary assurance to the customer that he is receiving the product he specified. Although the term "customer acceptance" is usually considered synonymous with "Government acceptance," the principles of this review should also apply to prime contractor acceptance of major subcontractor articles. The acceptance review is technically equivalent to the First Article Configuration Inspection (FACI) which is normally associated with a mass production contract. However, the usual characteristic of a NASA contract is limited, frequently singular, production. When more than one article is involved, the individual articles usually vary in configuration and flight objectives, so that an acceptance review and buy-off is necessary for each article.

Since there is available a NASA management guide, NPC 500-1 (ref. 5), which develops the FACI review for use on Apollo, we will start with that definition. Users of the present publication can modify that definiton to suit second and succeeding production articles; this will depend on the amount of variation from the first article.

FACI is defined by NASA NPC 500-1, "Apollo Configuration Management Manual" (ref. 5, exhibit XIV), as "a formal technical review which establishes the product configuration baseline." This reference goes on to state the specific tasks of FACI to be:

(1) Determine compatibility between released engineering and as-manufactured configuration
(2) Determine compatibility of qualified configuration to (1) above
(3) Determine validity of acceptance testing by comparison of test method and test data with the unit's performance and design requirements
(4) Insure that the initial submittal of customer-requested drawings and records be either the same as (or revisions of) those submitted for audit at the FACI

(5) If circumstances warrant, review and validate engineering release system and change control procedures

The FACI, therefore, consists of a step-by-step demonstration by the contractor that he is in compliance with the procurement specification(s). Because of the customer buy-off function as the result of this review, the output must be a simple "Yes, it does comply" or "No, it does not comply." Resolution of the latter result must be included in the review report. This might be in the form of corrective action to be accomplished or, in some cases, waiver items on DD Form 250, entitled "Material Inspection and Receiving Report."

The review may be divided into segments where the interactions can be separately evaluated. However, the segments must be clearly defined with no contingencies or exclusions. Preparatory effort requires reviews of individual components, since the documentation and data assembly task is too large collectively to be performed by a single acceptance review. It should also include physical inspection of the hardware to gain assurance of the quality of mechanical design and workmanship and to resolve mechanical questions which are best seen in three dimensions. Outputs from these preliminary reviews state "Yes, this component complies" or "No, these tasks must be completed prior to the formal review;" these statements are followed by a listing of the review findings. Then, too, the formal review may be facilitated by separation into subsystems and by individual teams pooling their findings at the conclusion of the separate reviews. The manner of segmentation is arbitrary as long as the summed results prove complete compatibility.

The scope of the formal acceptance review depends to a great extent on the thoroughness of documentation of the contractor's prior design review program. With an adequately documented review program, the formal acceptance review might cover only the system level and acceptance testing.

Review Team

The acceptance review is performed by top engineering and management personnel of the cognizant NASA installation, defined by NASA NPC 250-1 (ref. 2) as "that major organizational unit of NASA which has direct technical and managerial responsibility for the system under contract." This may be either a project at a NASA center or a program office at NASA Headquarters. Prior to review by either agency, there are many contractor internal reviews for the preliminary collection and organization of acceptance data. These meetings are usually conducted by contractor test integration personnel since the bulk of data gathered here is test-oriented. In this type of review, the designer is assisted by personnel from reliability, test, quality, and manufacturing to present supporting information as to hardware compatibility. The efforts culminate in a preparatory review by the contractor program manager who, in turn, leads the presentation to the customer acceptance review team.

Data Inputs

In order to determine compatibility between released engineering and as-manufactured configuration, data inputs must include updated assembly drawings, detail drawings, test specifications, manufacturing processes, and quality approval sheets for all manufacturing and assembly steps. Previous reviews may have produced adequate documentation to show compatibility between manufacturing procedures and released engineering as well as the capability of that engineering design to satisfy mission objectives. Internal contractor reviews now perform the step-by-step compliance inspection of the quality records of the manufactured article. Documentation of these reviews becomes part of the data package for the customer acceptance review.

For determination of the compatibility of the qualified component configuration with the manufactured version in the first article, the quality records for qualification test units are also submitted to the internal review. Any manufacturing changes resulting from qualification test failures are verified as having been included in the manufacturing procedures for deliverable hardware. These review findings as well as qualification test reports and customer signoff sheets also become part of the customer acceptance data packages.

All associated failure reports are presented in a problem status summary to indicate closure or implemented corrective action leading to closure of problems affecting the manufactured article. Individual failure reports are available on request of the review team. Reliability predictions and failure mode and effects analyses have been updated to include the contractor's experience during the development cycle. When the item is second or later in a series, failure experience and correction occurring too late to be covered in the flight readiness review of the preceding item should be another input at this point.

The system's test log, including final acceptance test in the presence of the customer, comprises another major input to the formal review. As previously stated, the validity of acceptance testing is determined by comparison of the method and data obtained with the performance and design requirements.

Configuration control procedures are sometimes submitted at this time as proof that subsequent system changes will be adequately documented and incorporated into existing hardware.

Data Outputs

The most significant data output from the acceptance review is the "Material Inspection and Receiving Report," DD Form 250, MSFC Form 71 (ref. 6) or an equivalent, constituting customer acceptance of the manufactured system. This document defines the terms of acceptance, including successfully completed requirements and waiver items. Waiver items describe conditional acceptance of the system although deviations from specified criteria exist. The waiver permits shipment and additional testing to occur concurrently with corrective action for the deviation. All waivers must be cleared prior to flight test (use) of the system.

The data compiled for an acceptance review might be considered to be an output in itself. The assembled qualification test and configuration data can be formalized and maintained in an updated condition to show current component configuration and its traceability to the qualified unit. Use history can be tabulated (if it has not been done previously) and appended by further usage. In short, the acceptance file can be updated as changes occur in order to facilitate flight readiness reviews or acceptance of future systems. It is possible that, if significant vehicle configuration change occurs, additional FACI's may be required.

SPECIAL PURPOSE REVIEWS

Several categories of review which might be considered outside of the scope of design reviews have become recognized techniques and are described briefly.

Flight Readiness Review

Immediately prior to the launch of any vehicle or payload, a final review is held to assure customer management that the system inherent reliability has not been degraded because of any laxness in technical or documentary discipline and that test experience subsequent to acceptance review has created no significant doubt of the capability of the flight hardware successfully to perform the mission. The review (or series of reviews, depending on the complexity of the system) is performed by teams of high-level personnel with sufficient authority to enforce their decisions. The team members are frequently, and most effectively, not directly connected with the program.

In programs of major complexity, it is usual for the prime contractor or the integration contractor and the major associates to have a review in depth prior to the customer's review. In the Gemini Launch Vehicle Program, for instance, the Launch Integrity Team (LIT) composed of high-level representatives from the several associate contractors reviewed each launch vehicle in depth prior to the flight safety review meeting with the customer. A similar technique was used by the contractor for the Atlas-Mercury launch vehicle. The flight readiness review program for the Apollo spacecraft program is defined in ref. 7.

The major input for this review is the problem status summary. Since the review team cannot cover a system to any real depth, it must establish its confidence in the system readiness by evaluating the program personnel's understanding of recognized problems, evaluating the efficacy of the fixes, and probing for soft areas in the technical story or its documentation. Obviously, documentation of the close-out of any waivers listed on the prior acceptance review (DD 250) must be presented.

Output is normally formalized in a relatively brief report since it will not be required as an input to other reviews. The output decision is whether or not to launch. It is obvious that the team needs considerable authority and stature for a "no-launch" decision. In the case of the contractor in-house reviews such as the LIT, the output is, in addition to the written report, a series of oral presentations to the customer review team.

System Readiness Review

The readiness review is a customer management function intended to provide a basis for buy-off of a particular portion of system assurance testing. The buy-off implies an integrity to proceed with further assurance functions. It is based generally on verification of the hardware and the test facilities and procedures to be used in the next event; often, it also covers certain critical safety aspects of the design. Specific detailed objectives include assuring that (1) no quality discrepancies are unresolved, (2) all prerequisite activities are accomplished, (3) no failures remain unexplained or uncorrected, and (4) a thorough set of controlling documents and procedures exists for the next assurance step. Particular check points include consent to test (CTT) and consent to ship (CTS). The acceptance review described in a previous section under "Acceptance Review" is the functional equivalent of CTS; the flight readiness review (above section) is a special case of CTT.

Postqualification Review

Design review is conducted upon completion of component qualification and prior to submittal of the qualification report to the customer to provide assurance that design and test revisions which have been made since release have not adversely affected design effectiveness, that all testing to date confirms the adequacy of the design solution, and that all changes to qualification units are reflected in the production hardware.

The review considers the results of qualification and special testing, the problems of prototype production, and all change control board action on the component detail drawings and test specifications since the last review. The value of this review increases with the amount of difficulty observed in qualification. The pressures to redesign and retest after failure can become quite intense and many things are accomplished with "paper work to follow." If further failures occur, the paper-work lag is increased. Additional complications are introduced by time lag and communications problems among the contractor, vendor, and test agency. At the completion of qualification testing the required number of units might have passed, but the lack of proper documentary control has resulted in extremely obscure development history. The task of design review ensures that (1) changes to the released configuration were qualified and were made prior to full production, (2) changes were inconsequential, or (3) retrofit of affected units has been undertaken. The postqualification review is conducted on each development component in the system.

The postqualification review team utilizes two types of personnel:

(1) Engineers experienced in environmental test and evaluation—those able to determine the cause and significance of test failures, fixes, retest validity, deviation from standard procedures, and so forth

(2) Engineers able to evaluate the effects of test results on subsystem performance (possibly members of the prerelease team)

The design is represented in this review by the qualification test engineer as well as by the designer, since both parties have first-hand knowledge and experience in testing the component. The manufacturing planner responsible for production hardware provides configuration information. The review team nucleus, as previously indicated, might consist of senior design, reliability, quality, and test engineers, preferably (but not necessarily) dissociated from the project.

In view of the contractual significance of the submittal of the formal qualification test report, customer participation in this review is not appropriate. The review is basically an internal work meeting designed to ensure the technical adequacy of qualification data. Customer attendance would tend to alter the meeting objective to that of an initial sales presentation. In this atmosphere, it would be impossible to evaluate objectively technical flaws which might require requalification, should such be the findings of the review team. The design review report will, of course, be available for customer review at his request roughly 1 week after the review. At this time, he can coordinate any comments or suggestions as to the data presentation in the formal qualification test report with the contractor test group.

It might be pointed out that customer signoff of the formal qualification test report approves the test of that particular component but does not imply concurrence with the system configuration which utilizes that component. The buy-off of system configuration occurs following the acceptance review.

The primary inputs to this review are the qualification test specification and procedure, data sheets and notes including any existing failure reports, failure analysis reports, and problem closures which are to be formalized into the qualification test report. Also included in this package are component drawings, procedures, and quality logs utilized in the manufacture and acceptance test of the qualification units (and deliverable hardware, if production is already in progress). Special production and test data (e.g., prototype units) not previously covered should be reviewed. Prerelease design review recommendations and management followup action will provide a reference for present discussions. Associated change control board paper work should be available. The tested hardware should be made available to the review team to permit on-the-spot evaluation of damage and rework.

As with previous reviews, the output will be a formal report to contractor management, generated by the review chairman, of the findings and recommendations with regard to input data. In this particular review, the major outputs deal with qualification and production phases of component acquisition.

The major output involving qualification could range from unconditional acceptance of the basis, procedure, and results to recommendation for partial or complete requalification. A second, equally important output finds complete conformance of production configuration to that qualified or recommends specific modifications to production procedures (and hardware if production is already in progress).

In addition to the immediate assurance benefits of the postqualification review, the output serves as part of the preparatory effort for the acceptance review. Documentation of this review, appended by the qualification test report, customer signoff sheets, and later similarity supplements for minor design revisions, is the basic input to the impending configuration inspection by the customer.

Subsystem Status Review

Purpose

The subsystem status review series establishes an assurance that all system study results, altered system objectives, changes to component design, development test data, and state-of-the-art advancements are receiving proper evaluation for pertinency to the subsystem configuration and that the configuration has been revised when necessary but not degraded in the process.

The occasion for reviews of this type sometimes arises in the development cycle of major systems when the time between previously identified milestones is quite long. Here, in view of the continuous influx of new information pertaining to system development at all levels, design review by other-than-project personnel is advisable on a periodic basis. For practical purposes, it is best to conduct these reviews by subsystem; component reviews are too numerous and system reviews, too unwieldy. The frequency of these status reviews would vary with the state of flux of design in each subsystem; however, a suggested interval would be every 6 to 8 months after the subsystem preliminary review.

Review Team

Technical department staffs of the contractor organization provide the personnel to conduct these reviews; preferably, they should be the same as those specialists involved in the preliminary subsystem review. The talents required will conform to the type of data predominantly available for review, progressing from theoretical studies to actual test results as development proceeds. The design is presented by the project engineer assigned responsibility for the subsystem under review.

The series of reviews affords ample opportunity for customer technical representatives to keep pace with contractor efforts; however, adequate preparation is again emphasized as an essential prerequisite to participation.

Input Documents

Inputs for this review are the subsystem specification, schematic, and description report, each updated to show current status of development. Specifications of major components are frequently applicable.

Supporting data cover a wide range of document types and actually include all study and test reports resulting from the design and development effort as well as a performance history of related (similar) projects. Problem investigation reports receive special attention elsewhere in the program organization and so are not stressed herein. Changes evolving from problem investigations will be reflected in the configuration data, and investigations in progress are best deferred to the next status review.

Assurance of complete data availability will be obtained in a manner consistent with the contractor organization. In general, PERT summaries or engineering directives will permit traceability of study and test data. Followup on prior review recommendations as acted upon by program management will provide a reference for initiating current discussions.

Output Report

The report of a subsystem status review will not follow a specific pattern since the type of data reviewed will vary during the course of development. The report will, of course, list data inputs and personnel, but items of its content will depend on specific areas of inquiry opened by the reviewers. The end product will be a judgment of design adequacy with possible recommendations of retest or additional test or study efforts in areas considered technically weak.

Functional Review

Occasionally, after the system preliminary review, situations will arise requiring reevaluation of some facet(s) of system configuration from a functional viewpoint rather than by physical subdivisions. The purpose might be to evaluate the results of special studies or tests or to judge the method of implementation of revisions to program philosophy. The material covered by this type of review usually encompasses more than one subsystem. A special function review would be held, for example, to reevaluate prelaunch hold and shutdown parameters, to consider weight reduction techniques, or to update reports on malfunction hazards, flight performance improvements, the master measurements list, and so forth. Such reviews would be conducted on an as-required basis by nonproject personnel whose capabilities would be defined by the function(s) being reviewed.

Failure Review

Reviews following failures are not subject to any specific set of directions. Extreme discipline is required to prevent the review from losing its objectivity because emotions tend to run high and potential contributors are still in a state of shock. Initial action requires the selection of a chairman with recognized authority who will impose this discipline on customer and contractor personnel alike.

CHAPTER 4

Application

The design review program for any particular contract is, of course, a subject of discussion and agreement between the contracting agency and the contractor. NPC 250-1, par. 3.6.1 (ref. 2), states that the design review program should be defined and submitted as part of the Reliability Program Plan. The review plan will contain a schedule of reviews (contractor and subcontractor reviews as applicable) by level and type. Certain generalizations can be accepted in the initial listings since all major components may not be identified, and initial schedules will be keyed to milestones. It is recognized that the principles of the design review process should be applied in different degrees to the various types of NASA contracts. In order to provide a basis for formulation of effective design review programs for the large variety of NASA programs, the following questions should be answered for the particular program:

(1) How important is the design review program to the achievement of reliability?
(2) Why does a formal review program achieve anything?
(3) How important are the assurance aspects of the design review program?

An adequate program can be planned once these questions are resolved. Chapter 5 provides a technique for estimating costs of the selected review plan. The design review program is a product assurance program and assists in the improvement of marginal designs through the early visibility given the design logic. It is the only technique for independent evaluation prior to the test program. Since problems found at a later date tend to be "fixed" rather than corrected, the importance of design review is evident.

The application of additional brainpower and experience to the design and development effort through design review enhances management visibility and permits more knowledgeable direction at the major design decision points. The result is product improvement.

The formal program provides timely assurance to contractor and customer management of the validity of technical decisions. The review disciplines of retention and presentation of decision logic and design data assure earlier attention to problem areas. The design review program is the principal technique which provides assurance to company and customer management prior to test and usage that the specification and the demonstrated capability of the product do satisfy the output criteria.

With this background, it is now possible to discuss applicability of a design review program in terms of program requirements. A program of national significance, such as a manned spacecraft, a man-rated launch vehicle, or a major space probe of the Surveyor or Voyager class, will require a complete design review program (both contractor and subcontractors), incorporating all the elements described in the preceding chapters. The program requirements for achievement of reliability and for assurance to company and customer management are very rigid, and any benefits which can be gained from the review program must be gained. The following listing illustrates that program:

(1) System preliminary design review (PDR)
(2) Subsystem PDR
    Guidance
    Flight controls
    Environmental control
    Communications

Range safety
Electrical
Hydraulic
Malfunction detection system
AGE
Structure
Etc.

(3) Component PDR
All major components
(4) Component PDR—Subcontractor
All major procured components
(5) Subsystem status reviews
All subsystems at 6-month intervals to first manned flight
(6) Component prepackage reviews
All major electronic and electromechanical components
(7) Component prerelease reviews
All major components
(8) Component postqualification reviews
All components in test program
(9) Acceptance review
All end items
(10) Flight readiness reviews
Prior to each flight

Chapter 5 presents the visible costs of full application of those requirements of two representative programs, a man-rated launch vehicle and a lunar hard-landing probe.

Programs of lesser complexity or significance can have review programs scaled to the increased inherent visibility of the less complex item. A relatively simple scientific experiment designed to be launched piggyback from another system can possibly be covered with a conceptual review, a prerelease review, and a flight-readiness review.

There are, of course, many possible variations between these two extremes, dependent upon the degree of reliability achievement desired and the assurance required by the customer. The following list presents a review program plan for a hypothetical unmanned satellite system or new launch vehicle stage:

(1) System PDR
(2) Component PDR
Major components
(3) Component prerelease review
Newly designed major components
(4) Acceptance review
End items
(5) Flight-readiness review
End items

The requirements of NPC 250-1 (ref. 2) are applied at a level commensurate with the design challenge and the significance and expense of the program. In this case, the maximum review program is not required and conceptual reviews are limited to system and major components. Prerelease reviews are held on major components, and an acceptance review and a flight-readiness review are held on the end item. Chapter 5 presents a cislunar micrometeoroid detector as an example of this class of program.

Similarly, a program utilizing proven hardware for a new purpose (e.g., man-rating Atlas D for Mercury use), may require heavy emphasis on the assurance aspects of the design review program with greatly reduced emphasis on design change to improve the reliability of the hardware.

CHAPTER 5

Costs

Application of the precepts of this manual can be expected to result in a reduction of end costs of any program through prudent and timely investment of manpower to reduce the larger cost risks of subsequent failure. However, it is equally necessary to provide guidance for use in making initial program cost estimates for the apparent costs of design review programs.

Frequently we find that the documentation disciplines necessary for technical control and substantiation of a development program have been neglected. It then becomes quite costly to substantiate the development after the fact; however, such costs should not be chargeable to the design review program costs. It has been mentioned before that one of the major benefits of the review program for the achievement of reliability is derived from the documentation disciplines which are necessary to substantiate the development effort. Any program having a valid reliability criterion (either quantitative or qualitative) should be sufficiently well documented that no efforts other than collection and distribution of existing documents (not just data) are necessary. The review program costs derived herein presume that this discipline has been exercised.

In order to develop an estimate of apparent costs we have utilized a review program format based on the ground rules contained in the earlier chapters of this manual. Starting with individual reviews (system preliminary, component prerelease, etc.), we have established manpower complements which by virtue of their specialized talents are believed capable of accomplishing the review task. Tables 1 to 24 present complements of reviewers and other contributors along with estimated preparation and meeting time allotments. These individual complements may be applied to programs of varying complexity and national significance to gain some measure of the visible costs of design review in proportion to overall engineering effort.

EXAMPLES OF PROGRAMS

Man-Rated Launch Vehicle

A man-rated launch vehicle can be considered as an example of a program of national significance, as mentioned in chapter 4. The design and development, exclusive of the engines, could cost approximately $200 million if the design were just now being proposed. The engineering proposal should include design review as a separate task item (as part of the Reliability Program Plan) with an estimated component breakdown and design review plan time-phased with the engineering effort. Tables 25 and 26 present part of the information to be included in a similar proposal of a program of this magnitude. Further schedule presentations may be employed to integrate the element of review frequency into the proposal. This presentation might be visualized as a chart of system, subsystem, and component listings along one axis with program time along the other axis; each component listing would show estimated checkpoints where design reviews are planned. Or it might be simply a list identifying the system components as to complexity, type (electrical, electromechanical, or mechanical), and development status including prior use or new use.

Application of the individual man-hour totals as estimated in tables 1 to 24 results in a review program effort totaling some 44,800 man-hours. This estimate amounts to about 1.1 percent of the total engineering manpower required for the definition and acquisition phases.

Major Space Probe

A major space probe of relatively high complexity and national significance is selected as another example. As in the case of the manned launch vehicle, full application of the proposed review techniques was suggested.

Tables 27 and 28 present the component breakdown and program of reviews which represent about 24,600 man-hours. A comparison with total proposed engineering man-hours is not available.

Several distinct features of this example should be mentioned. First, the above effort is limited to a late configuration. Additional review effort would have to be apportioned for the design of the lunar survival package and additional sensors that were a part of earlier configurations. Second, both the spacecraft "bus" and the television system components are included in the example. Roughly 20 percent of the total manpower estimate would be performed by the television system subcontractor. Third, the Central Computer and Sequencer (CC&S) package is too complex to be handled as a component and would probably be best handled as a subsystem by frequent status reviews. Also the power subsystem consists mainly of two types of component (solar panels and storage batteries) and would probably not require subsystem reviews. The six subsystems indicated are:

(1) Radio, data encoder, and command subsystem
(2) Central computer and sequencer subsystem
(3) Attitude-control subsystem
(4) Midcourse propulsion subsystem
(5) Television subsystem
(6) Group support and data recovery

Unmanned Satellite System

A design review program of lesser proportions would probably be utilized in the development of an unmanned satellite system, say a cislunar micrometeoroid detector. Assuming a design aimed primarily at obtaining penetration data (but also recording and relaying secondary measurements), we have a program value in the $20 to $25 million range for the satellite and test phases, while the total program value might reach $40 million. Tables 29 and 30 present the design review effort suggested. The major components (average and high complexity) can be adequately covered with two reviews, preliminary and prerelease. The system level effort consists of a preliminary review, an acceptance review, and a flight-readiness review. A factor compensating for the reduction in review coverage is added inherent visibility of the more compact working force.

This amounts to a design review program effort of 8500 man-hours. By utilizing a fairly conservative estimate of 500,000 man-hours for total engineering effort to develop the satellite and AGE checkout equipment, the review program amounts to about 1.7 percent of that total.

COMPARISON WITH INDUSTRY PRACTICES

By way of comparison, an Aerospace Industries Association survey of industry design review practices (ref. 15) showed between 1 and 28 percent of design man-hours were expended for this purpose, with a typical figure of 5 percent. If it is assumed that design effort is about 35 to 50 percent of total engineering effort (the remainder being test site activation, test, systems integration, reliability, quality assurance, program planning and control, fabrication, etc.), the typical figure given above falls between 1.7 and 2.5 percent. We have presented the examples in terms of total engineering effort since that reference has more validity for a design review program which must evaluate not only design but assurance efforts also.

The conclusion to be reached from this discussion is that, in costing a design review program, project management must adapt the review effort to program complexity and significance, with the actual manpower allocation being about 1 or 2 percent of the total engineering effort.

Table 1.—System Preliminary Review—High Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Chief engineer (contractor): chairman	88	32	120
Sr. design specialists (3)	144	96	240
Design specialist (1 per subsystem; 10 subsystems)	480	320	800
Staff reliability engineer	48	32	80
Customer systems engineer	...	...	...
Customer design and test specialists (3)	...	...	...
			1240
Other participants			
System engineer (technical director)	0	32	32
Subsystem design (1 per subsystem)	0	320	320
Reliability manager	0	32	32
Maintainability	0	32	32
Safety	0	32	32
Human factors	0	32	32
Value	0	32	32
Quality control	48	32	80
Manufacturing	48	32	80
			672
			1912

Table 2.—System Preliminary Review—Average Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Chief engineer (contractor): chairman	64	28	92
Staff reliability engineer	36	28	64
Sr. design specialist (2)	72	56	128
Design specialist (1 per subsystem; 7 subsystems)	252	196	448
Customer system engineer	...	...	...
Customer design and test specialists (3)	...	...	...
			732
Other participants			
System engineer (technical director)	0	28	28
Subsystem design (1 per subsystem)	0	196	196
Reliability manager	0	28	28
Maintainability	0	28	28
Safety	0	28	28
Value	0	28	28
Human factors	0	28	28
Quality control	36	28	64
Manufacturing	36	28	64
			492
			1224

Table 3.—System Preliminary Review—Low Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Chief engineer (contractor): chairman	48	24	72
Design specialist (1 per subsystem; 4 subsystems)	144	96	240
Staff reliability engineer	36	24	60
Customer system engineer	...	...	...
Customer design specialists (2)	...	...	...
			372
Other participants			
System engineer (technical director)	0	24	24
Subsystem design (1 per subsystem)	0	96	96
Reliability manager	0	24	24
Safety	0	24	24
Quality control	36	24	60
Manufacturing	36	24	60
			288
			660

Table 4.—Subsystem Preliminary Review (Airborne)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	48	16	64
Design specialist	24	16	40
Sr. Design specialists (2)	48	32	80
Staff reliability engineer	24	16	40
Circuit specialist	24	16	40
			264
Other participants			
Subsystem design	0	16	16
Reliability engineer	0	16	16
Maintainability	0	16	16
Human factors	0	16	16
Value	0	16	16
Quality control	16	16	32
Customer design and test specialists (2)	...	...	...
			112
			376

Table 5.—Subsystem Preliminary Review (Age)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	48	16	64
Design specialist	24	16	40
Sr. design specialists (2)	48	32	80
Staff reliability engineer	24	16	40
Circuit specialist	24	16	40
			264
Other participants			
Subsystem design	0	16	16
Reliability engineer	0	16	16
Maintainability	0	16	16
Human factors	0	16	16
Safety	0	16	16
Quality control	16	16	32
Customer design and test specialists (2)	...	...	...
			112
			376

Table 6.—Subsystem Status Review (Airborne)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	32	12	44
Sr. design specialist	32	24	56
Staff reliability engineer	16	12	28
Circuit specialist	16	12	28
			156
Other participants			
Subsystem design	0	12	12
Reliability engineer	0	12	12
Maintainability	0	12	12
Value	0	12	12
Quality control	12	12	24
Customer design and test specialists (2)	...	...	...
			72
			228

Table 7.—Subsystem Status Review (Age)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	32	12	44
Sr. design specialist	32	24	56
Staff reliability engineer	16	12	28
Circuit specialist	16	12	28
			156
Other participants			
Subsystem design	0	12	12
Reliability engineer	0	12	12
Maintainability	0	12	12
Safety	0	12	12
Quality control	12	12	24
Customer design and test specialists (2)	...	...	...
			72
			228

Table 8.—Component Preliminary Review—High Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	28	12	40
Sr. design specialists (2)	24	24	48
			88
Other participants			
Subsystem design	0	12	12
Component design	0	12	12
Reliability engineer	0	12	12
Human factors	0	12	12
Maintainability	0	12	12
Value	0	12	12
Quality control	12	12	24
Manufacturing	12	12	24
Customer design specialist	...	...	...
			120
			208

Table 9.—Component Preliminary Review—Average Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	24	8	32
Sr. design specialist	8	8	16
Design specialist	8	8	16
			64
Other participants			
Subsystem design	0	8	8
Component design	0	8	8
Reliability engineer	0	8	8
Quality control	8	8	16
Manufacturing	8	8	16
Customer design specialist	...	...	...
			56
			120

Table 10.—Component Preliminary Review—Low Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	12	4	16
Design specialist	4	4	8
Reliability engineer	4	4	8
			32
Other participants			
Component design	0	4	4
Customer design specialist	...	...	...
			4
			36

Table 11.—Component Prepackaging Review—High Complexity (Electronic or Electromechanical Designs Only)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	32	8	40
Packaging specialist	8	8	16
Circuit specialist	16	8	24
Staff reliability engineer	16	8	24
			104
Other participants			
Subsystem design	0	8	8
Component design (circuits)	0	8	8
Component design (packaging)	0	8	8
Maintainability	0	8	8
Customer design specialist	...	...	...
			32
			136

Table 12.—Component Prepackaging Review—Average Complexity (Electronic or Electromechanical Designs Only)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: Chairman	26	6	32
Circuit specialist	10	6	16
Packaging specialist	10	6	16
Reliability engineer	10	6	16
			80
Other participants			
Component design (circuits)	0	6	6
Component design (packaging)	0	6	6
			12
			92

Table 13.—Component Prerelease Review—High Complexity (Electronic or Electromechanical Designs Only)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	32	8	40
Circuit specialist	8	8	16
Packaging specialist	8	8	16
Staff reliability engineer	16	8	24
Environments specialist	8	8	16
Manufacturing	16	8	24
			136
Other participants			
Subsystem design	0	8	8
Component design (packaging)	0	8	8
Maintainability	0	8	8
Quality control	8	8	16
			40
			176

Table 14.—Component Prerelease Review—High Complexity (Mechanical Designs Only)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	32	8	40
Packaging specialist	8	8	16
Staff reliability engineer	16	8	24
Environments specialist	8	8	16
Manufacturing	16	8	24
			120
Other participants			
Subsystem design	0	8	8
Component design (packaging)	0	8	8
Maintainability	0	8	8
Quality control	8	8	16
			40
			160

Table 15.—Component Prerelease Review—Average Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	28	4	32
Reliability engineer	12	4	16
Environments specialist	12	4	16
Manufacturing	12	4	16
			80
Other participants			
Subsystem design	0	4	4
Component design (packaging)	0	4	4
Maintainability	0	4	4
Quality control	12	4	16
			28
			108

Table 16.—Component Postqualification Review—High Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	18	6	24
Staff reliability engineer	10	6	16
Environments specialist	10	6	16
Quality control	10	6	16
			72
Other participants			
Component design	0	6	6
Test conductor	0	6	6
Manufacturing	10	6	16
			28
			100

Table 17. —Component Postqualification Review—Average Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	12	4	16
Reliability engineer	4	4	8
Environments specialist	4	4	8
Quality control	4	4	8
			40
Other participants			
Component design	0	4	4
Test conductor	0	4	4
Manufacturing	4	4	8
			16
			56

Table 18. —Component Postqualification Review—Low Complexity

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	6	2	8
Environments specialist	2	2	4
			12
Other participants			
Component design	0	2	2
Test conductor	0	2	2
			4
			16

Table 19.—Combined Prerelease/Postqualification Review—High Complexity (Prior Usage Components)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	40	8	48
Design specialist	16	8	24
Staff reliability engineer	14	8	22
Environments specialist	14	8	22
Quality control	14	8	22
			138
Other participants			
Subsystem design	0	8	8
Component design	0	8	8
Maintainability	0	8	8
Reliability engineer	0	8	8
Manufacturing	14	8	22
			54
			192

Table 20.—Combined Prerelease/Postqualification Review—Average Complexity (Prior Usage Components)

	Preparation, hr	Meeting, hr	Total, hr
Review team			
Design specialist: chairman	34	6	40
Reliability engineer	12	6	18
Environments specialist	12	6	18
Quality control	12	6	18
			94
Other participants			
Subsystem design	0	6	6
Component design	0	6	6
Maintainability	0	6	6
Manufacturing	12	6	18
			36
			130

Table 21.—Preacceptance Review (Contractor Preparation)
[Average-3 Hours Per Subsystem, N Subsystems]

	Preparation, hr
Conducted by program manager	3N
Other participants	
System engineer (technical director)	3N
Project engineers (reliability, test, safety, design)	12N
Quality control manager	3N
Subsystem design	3N
Subsystem manufacturing representative	3N
Subsystem reliability representative	3N
Subsystem test representative	3N
Subsystem quality control representative	3N
	36N

Table 22.—Acceptance Review (Customer)
[N Subsystems]

	Preparation, hr	Meeting, hr	Total, hr
Review team (customer)			
Customer design specialist: chairman		...	...
Customer design and test specialists (approx 4)		...	...
Other participants (contractor)			
Program manager	Preacceptance	40	40
System engineer (technical director)		40	40
Project engineers (reliability, test, safety, design)		160	160
Subsystem design		40N	40N
Manufacturing		40	40
Quality control manager		40	40
		320 +	40N

Table 23.—Preflight Readiness Review (Contractor Preparation)
[Meeting Estimate—16 Hr]

	Preparation, hr
Review team	
Chief engineer: chairman	16
Program manager	16
Site manager	16
	48
Other participants	
System engineer (technical director)	16
Project engineers (reliability, test, safety, design)	64
Subsystem design (N subsystems)	16N
Quality control manager	16
Manufacturing	16
Site test engineers (approx 4)	64
Site quality control	16
Site safety	16
	208 + 16N
	256 + 16N

Table 24.—Flight-Readiness Review (Customer)
[Meeting Estimate—16 Hr]

	Preparation, hr	Meeting, hr	Total, hr
Review team (customer)			
Customer design specialist: chairman	...	...	...
Customer design and test specialists (approx 4)	...	...	...
Other participants (contractor)			
Chief engineer	Preflight readings	16	16
Program manager		16	16
System engineer (technical director)		16	16
Project engineers (reliability, test, safety, design)		64	64
Subsystem design (N subsystems)		16N	16N
Manufacturing		16	16
Quality control manager		16	16
Site test engineers (approx. 4)		64	64
Site quality control		16	16
Site safety		16	16
Site manager		16	16
			256 + 16N

Table 25. —Man-Rated Launch Vehicle Component Breakdown[a]

Component	Total	Electronic or electromechanical		Mechanical	
		Prior use	New	Prior use	New
High complexity	20	9	9	2	0
Average complexity	31	16	10	5	0
Low complexity	49	17	13	17	2
Total	100	42	32	24	2

[a]Based on component information contained in ref. 8.

Table 26. —Man-Rated Launch Vehicle Design Review Program

No. of reviews	Review type
1	System preliminary review (high complexity)
10	Subsystem preliminary reviews
30	Subsystem status reviews
1	Acceptance review with prior internal review
12	Flight readiness reviews with prior internal reviews
20	High-complexity component preliminary reviews
31	Average-complexity component preliminary reviews
49	Low-complexity component preliminary reviews
9	High-complexity component prepackaging reviews
10	Average-complexity component prepackaging reviews
9	High-complexity component prerelease reviews (elec)
0	High-complexity component prerelease reviews (mech)
10	Average-complexity component prerelease reviews (all)
11	High-complexity component combined reviews (prior use)
21	Average-complexity component combined reviews (prior use)
9	High-complexity component postqualification reviews
10	Average complexity component postqualification reviews
49	Low-complexity component postqualification reviews

Table 27. —Major Space Probe Component Breakdown[a]

Component	Total	Electronic or electromechanical	Mechanical
High complexity	12	9	3
Average complexity	17	15	2
Low complexity	17	14	3
Total	46	38	8

[a]Based on component information contained in refs. 9-13.

Table 28. —Major Space Probe Design Review Program

Number		Review type
Prime contractor	Subcontractor	
1	0	System preliminary review (high complexity)
5	1	Subsystem preliminary reviews
15	3	Subsystem status reviews
1	0	Acceptance review with prior internal reviews
4	0	Flight readiness reviews
8	4	High-complexity component preliminary reviews
13	4	Average-complexity component preliminary reviews
14	3	Low-complexity component preliminary reviews
6	3	High-complexity component prepackaging reviews
12	3	Average-complexity component prepackaging reviews
6	3	High-complexity component prerelease reviews (elec)
2	1	High-complexity component prerelease reviews (mech)
13	4	Average-complexity component prerelease reviews (all)
8	4	High-complexity component postqualification reviews
13	4	Average-complexity component postqualification reviews
14	3	Low-complexity component postqualification reviews

Table 29. —Unmanned Satellite System Component Breakdown[a]

Component	Total	Electronic or electromechanical	Mechanical
High complexity	9	9	0
Average complexity	11	10	1
Low complexity	12	7	5
Total	32	26	6

[a]Based on estimated component structure contained in ref. 14.

Table 30. —Unmanned Satellite System Design Review Program

No.	Review type
1	System preliminary review (average complexity)
9	Component preliminary reviews (high complexity)
11	Component preliminary reviews (average complexity)
9	Component prerelease reviews (high complexity)
11	Component prerelease reviews (average complexity)
1	Acceptance review (approx 6 subsystems)
1	Flight readiness review

APPENDIX A

Definitions

The following definitions apply to the terms used in this publication.

Acceptance: The act of an authorized representative of the Government by which the Government assents to its ownership of existing and identified articles or approves specific services rendered as partial or complete performance of the contract (ref. 3).

Aerospace ground equipment: All equipment required on the ground to make an aerospace system operational in its intended environment (ref. 16).

AGE: Aerospace ground equipment.

Article: A unit of hardware or any portion thereof required by the contract (ref. 3).

Associate contractor: The contractor who under direct contract to NASA performs work excluded from the principal contract. The associate contractor is responsible to the principal contractor for technical integration of the (sub) system and must coordinate technical developments and requirements in a timely and organized manner. The associate contractor is directly responsible to NASA for administrative and contractual matters (ref. 16).

Baseline configuration: The documented and approved design concept or arrangement of components as established at a given point in the procurement cycle for systems or equipment (ref. 16).

Block diagram: A line drawing with block outlines to designate units or functional groups for general arrangement studies, functional explanation, product familiarization, etc. within a system, set, or item (ref. 16).

Breadboard: An assembly of preliminary circuits or parts used to prove the feasibility of a device, circuit, system, or principle without regard to the final configuration or packaging of the parts (ref. 16).

Checklist: A list of procedures or items summarizing the activities required for an operator or technician in the performance of his duties; a condensed guide; an on-the-job supplement to more detailed job instructions (ref. 16).

Chief engineer: That person in charge of all technical activity in an organization.

Circuit: A group of elements or parts, connected and related so as to perform a specific function in a component, assembly, or system (ref. 16).

Cislunar: Of or pertaining to space between the Earth and the orbit of the Moon or to a sphere of space centered on the Earth with a radius equal to the distance between the Earth and the Moon (ref. 16).

Cognizant NASA installation: That major organizational unit of NASA which has direct technical and managerial responsibility for the system under contract (ref. 2).

Component: A combination of parts, subassemblies, or assemblies, usually self-contained, which performs a distinctive function in the operation of the overall equipment; a "black box" (ref. 2).

Conceptual phase: That period in the system life cycle which usually terminates with publication of a specific operational requirement (ref. 16).

Configuration: The technical and physical description required to fabricate, test, accept, operate, maintain, and logistically support systems or equipment (ref. 16).

Configuration control: Systematic evaluation, coordination, approval, or disapproval of all changes to the baseline configuration (ref. 16).

Consent to ship: Customer buy-off function prior to transporting end item to field.

Consent to test: Customer buy-off function prior to major ground test or launch.

Contract: The agreement formally executed by the Government and the prime contractor which requires performance of services and/or delivery of a product at a cost to the Government, in accordance with terms and conditions set forth therein (ref. 2).

Contractor: Any person, partnership, company, or corporation (or any combination of these) which is a party to a contract with the United States Government (ref. 2).

Critical path: That particular sequence of activities that has the greatest negative or least positive activity slack (ref. 16).

CTS: Consent to ship.

CTT: Consent to test.

Design criteria: Standards upon which a design is based (ref. 16).

Design review program: A systematized and disciplined application of the broad technical competence of the contractor and the customer to a product. The program is intended to improve the product and to provide assurance to contractor and customer management, by formalized documentation of the decision logic, that the most satisfactory design has been selected to meet the program requirements.

Design specification: A document prescribing criteria to be satisfied in designing a particular component, subsystem, or system (or part). Typical criteria include performance requirements under specified environments, interface requirements, size, weight, ruggedness, safety margins, derating factors, and apportioned reliability goal (with definition of failure) (ref. 2).

Designated representative: An individual (such as a NASA plant representative), firm (such as an assessment contractor), or Government agency designated and authorized by NASA to perform a specific function(s) relative to the contractor's reliability effort; e.g., monitorship, assessment, and design review participation and/or approval of certain documents or actions (ref. 2)

Detail drawing: Delineates information to describe an item and shall include materials, finish, tolerances, and other requirements as applicable (ref. 16).

Detail specification: A detail description of a particular model of an item prepared by the designer which cites all specific design and construction criteria (ref. 16).

Development: The application of known techniques and principles to produce a desired result from the discoveries of research. In the development stage a device is visualized and its performance is anticipated. Development is characterized by deliberate planning, by ingenuity, and by synthesis of knowledge in many fields. The result of development is the creation of plans or models for a new device and the demonstration by test that the prototype of the device fulfills the objective of the development (ref. 16).

Deviation: A specific authorization, granted before the fact, to depart from a particular requirement of specifications or related documents (ref. 3).

End item: A space system or any of its principal system or subsystem elements; for example, launch vehicle, spacecraft, ground support system, propulsion engine, or guidance system. Also, articles covered by major subcontracts where NPC 200-2 is invoked by the NASA installation or by a system prime contractor. Also, articles which will be delivered direct to a Government installation or provided as GFP to a contractor (ref. 3).

Feasibility study: The phase during which studies are made of a proposed item or technique to determine the degree to which it is practicable, advisable, and adaptable for the intended purpose (ref. 16).

First article configuration inspection (FACI): A formal technical review which establishes the product configuration baseline (ref. 5).

GLV: Gemini launch vehicle.

Installation drawing: Shows general configurations, attaching hardware, and information to locate, position, and mount an item relative to fixed points and to other items (ref. 16).

Integration: The process of assuring that the major elements of a program be conceived, designed, assembled, tested, operated, and documented in such a manner as to be compatible with each other and to satisfy the program objectives (ref. 16).

Interface: The point or area where a relationship exists between two or more parts, systems, programs, persons, or procedures wherein physical and functional compatibility is required (ref. 16).

Interface drawing: The engineering drawing which graphically or descriptively displays the conditions of the interface which exist between assemblies (ref. 16).

Launch integrity team: Review team composed of high-level representatives of the prime contractor, or the integration contractor and the major associates, to review each Gemini Launch Vehicle prior to the customer flight-readiness review.

Launch vehicle: The part of the space vehicle which furnishes the propulsion and guidance during the initial part of the trajectory to provide the prescribed velocity, position, and attitude required for injection into the desired trajectory. Launch vehicles are commonly called boosters and consist of two or more propulsive stages (ref. 16).

LIT: Launch integrity team.

Man-rated space vehicle: Space vehicles for manned flight which have achieved the standards of performance and reliability previously established as reasonably acceptable for this class of equipment (ref. 16).

Milestone: Any significant event in the design and development of a space system or in the associated reliability program which is used as a control point for measurement of progress and effectiveness or for planning or redirecting future effort. Reliability program milestones should be identified in the reliability program plan (ref. 2).

Mission task: The specified purpose for which a device must perform (ref. 16).

NASA: National Aeronautics and Space Administration.

National Aeronautics and Space Administration: Civilian agency with research and development jurisdiction in aeronautical and space activities, except those activities peculiar to and primarily associated with the development of weapons systems and military operations (ref. 16).

Nonstandard part: One for which no published standard or specification exists (ref. 16).

NSRA: Nonstandard request authorization.

Operational: Equipment for which all research and development has been completed with achievement of performance objectives (ref. 16).

Operational phase: The period from acceptance by the user of the first operating unit until disposition of the system equipment. The operational phase overlaps the acquisition phase (ref. 16).

Part: One piece or two or more pieces joined together which are not normally subject to disassembly without destruction (ref. 2).

PERT: Program evaluation and review technique.

Piggyback experiment: An experiment which rides along with the primary experiment on a space-available basis without interfering with the mission of the primary experiment (ref. 16).

Prime contractor: A contractor with total system responsibility for the execution of work on contract to a Government agency. This includes all functional and administrative responsibilities necessary to satisfy contract requirements. Major programs can be established with separate prime contractors for essentially independent systems, but each will perform as a contractual entity with respect to the contracting agency (ref. 16).

Program: A related series of undertakings designed to accomplish a broad scientific or technical goal. Attainment of such long-range goals may be accomplished by implementation of specific projects (ref. 16).

Program evaluation and review technique: Method of charting events and obtaining predicted performance in accordance with a schedule (ref. 16).

Project: A scheduled undertaking, within a program, which may involve the research and development, design, construction, and operation of system and associated hardware, or hardware only, to accomplish a scientific or technical objective (ref. 16).

Qualification: Determination by a series of tests and examination of documents and processes that a part, component, subsystem, or system is capable of meeting performance requirements prescribed in the purchase specification or other documents specifying the adequate performance capability for the item in question (ref. 2).

Redundancy (of design): The use of more than one means of accomplishing a given task or function where all must fail before there is an overall failure of the system (ref. 2).

Schematic diagram: A diagrammatic drawing that shows function symbols with interconnections to illustrate circuit operation. It does not necessarily identify physical location of components or connections between them (ref. 16).

Space system: A system of equipment consisting of launch vehicle(s), spacecraft, ground support equipment, and test hardware, used in ground testing, launching, operating, and maintaining space vehicles or spacecraft (ref. 2).

Subcontract: A formal contract between a prime contractor to the Government and another concern or individual(s) (first tier subcontract) requiring performance of services and/or delivery of a product required in connection with the prime contract, or a similar contractual agreement between a first tier subcontractor and another concern (second tier) (ref. 2).

Subcontractor: A concern or individual(s) entering into a contract with the prime contractor or with a subcontractor in a tier higher than his own for services or a product required for the prime contract or a subcontract (ref. 2).

System: One of the principal functioning entities comprising the project hardware and related operational services within a project or flight mission. Ordinarily, a system is the first major subdivision of project work. Similarly, a subsystem is a major functioning entity within a system. (A system may also be an organized and disciplined approach to accomplish a task; e.g., a failure-reporting system.) (ref. 2).

Systems engineering: The process of applying science and technology to the study and planning of a system so that the relationships of various parts of the system and the utilization of various subsystems are fully established before designs are committed (ref. 16).

Vehicle acceptance test: System and subsystem test to ensure vehicle specification compliance before vehicle is accepted for flight use (ref. 16).

Waiver: Granted use or acceptance of an article which does not meet specified requirements (ref. 3).

References

1. Anon.: Design Review Requirements. NASA SR-Qual-66-1 MSFC, Jan. 20, 1966.

2. Anon.: Reliability Program Provisions for Space System Contractors. NASA NPC 250-1.

3. Anon.: Quality Program Provisions for Space System Contractors. NASA NPC 200-2.

4. Shipley, William F.; and Maclay, James E.: Mariner 4 Environmental Testing. Astronaut. Aeron., vol. 3, no. 8, Aug. 1965, pp. 42-48.

5. Anon.: Apollo Configuration Management Manual. NASA NPC 500-1.

6. Anon.: Material Inspection and Receiving Report. NASA Marshall Space Flight Center Form 71, July 1960.

7. Anon.: Apollo Spacecraft Program Office Spacecraft Flight Readiness Review Procedure. NASA MSC-A-D-66-6, Oct. 1966.

8. Gross, L.: GLV Summary of Component Qualification and Similarity Certification. Rev. A, Martin Co. Rept. LV282, Jan. 1965.

9. Lee, D.: Development of the Midcourse Trajectory-Correction Propulsion System for the Ranger Spacecraft. JPL Tech. Rept. 32-335, Mar. 1963.

10. Turk, W.: Ranger Block III Attitude Control System. JPL Tech. Rept. 32-663, Nov. 1964.

11. Benson, M.; and Williams, R.: Description and Flight Analysis of the Ranger VII TV Subsystem. JPL Tech. Rept. 32-680, Feb. 1965.

12. Kindt, D.; and Staniszewski, J.: The Design of the Ranger Television System to Obtain High-Resolution Photographs of the Lunar Surface. JPL Tech. Rept. 32-717, Mar. 1965.

13. Berman, A.: Tracking System Data Analyses Report—Ranger VII Final Report. JPL Tech. Rept. 32-719, June 1965.

14. Weissmann, E.: Conceptual Study of a Micrometeoroid Deep Space Satellite. Martin Co. Rept. ER 13700, Jan. 1965.

15. McClure, J.; and Winlund, E.: Design Review—A Philosophy, Survey, and Policy. Proc. Ninth Natl. Symposium on Reliability and Quality Control, Jan. 1963, pp. 287-300.

16. Anon.: .Apollo Terminology. NASA SP-6001, 1963.

Bibliography

Anon.: Design Review—Department Policy. Gen. Elec. Missile and Space Vehicle Department Policy 3.11, Sept. 1960.

Anon.: Engineering Design Review. Martin Co. Rept. ER 12701, 1962.

Anon.: Engineering Reviews Operating Procedure. Rev. 1, Martin Co. Rept. OP-B2.213, Jan. 1965.

Anon.: GLV Reliability Program Plan. Martin Co. Rept. ER 12256C, Nov. 1964.

Anon.: Implementation and Monitoring Techniques for NASA NPC 250-1 Reliability Programs. Martin Rept. ER 13386P, Mar. 1964.

Anon.: Procedures for Conduct of Preliminary Design Reviews and Critical Design Reviews. AFBSD Exhibit 61-55, Mar. 1962.

Anon.: Requirements for Reliability Program (for Systems and Equipments). MIL-STD-785, June 1965.

Boss, R.: Component Development Procedure. Martin Co. Rept. ER 13266, Dec. 1963.

Earles, D.: Reliability Application and Analysis Guide. Rev. 1, Martin Co. Rept. MI-60-54, July 1961.

Kaufman, R.; Corrigan, R.; and Bauer, H.: Why System Engineering and System Functional Analysis for Total System Design. Douglas Aircraft, Jan. 1965.

Smith, M.: Design Review. Proc. Tenth Natl. Symposium on Reliability and Quality Control, Jan. 1964, pp. 310-313.

NASA-Langley, 1967

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